PORTLAND HARBOR SUPERFUND SITE

TECHNICAL MEMORANDUM: EVALUATING STEADY-STATE AQUATIC FOOD WEB MODELS FOR THE PORTLAND HARBOR SUPERFUND SITE

DRAFT

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AWA	area-weighted average
BSAF	biota-sediment accumulation factor
DL	detection limit
DOC	dissolved organic carbon
dw	dry weight
EPA	US Environmental Protection Agency
EPI	Estimated Program Interface
ERA	ecological risk assessment
GIS	geographic information system
IDW	inverse distance weighting
ISA	initial study area
K_{OW}	octanol-water partition coefficient
MLLW	mean lower low water
ND	not detected
NLOC	non-lipid organic carbon
OC	organic carbon
ODEQ	Oregon Department of Environmental Quality
PCB	polychlorinated biphenyl
POC	particulate organic carbon
POP	persistent organic pollutant
RI/FS	remedial investigation/feasibility study
RPD	relative percent difference
SPMD	semi-permeable membrane device
TOC	total organic carbon
USACE	US Army Corps of Engineers
USGS	US Geological Survey
ww	wet weight

1.0 INTRODUCTION

As part of the Portland Harbor Remedial Investigation/Feasibility Study (RI/FS), the nature and extent of chemical contamination in sediment, water, and tissue is being characterized. These data will be used to characterize risk from exposure to these chemicals in the ecological and human health risk assessments. Based on these risk estimates, decisions will be made on the need for cleanup of contaminated sediments and/or control of upland chemical sources. The objective of sediment cleanup is to reduce chemical concentrations in fish to acceptable levels. Consequently, cleanup decisions associated with unacceptable risks from chemicals in fish must consider the relationship between chemical concentrations in sediment, water, and fish. One method to evaluate such a relationship is via use of a food web model. Several types of models have been developed to predict relationships between chemical concentrations in sediment and fish tissue. The food web models evaluated in this memorandum relate the concentrations of hydrophobic, nonionic chemicals in sediment and water with biota tissue residues, based on the characteristics of the chemical as well as the food web structure and species composition.

1.1 OBJECTIVES

The primary objective of food web modeling for the RI/FS is to develop a predictive relationship between chemical concentrations in sediment, water, and tissue. If this relationship can be established, the model may be helpful in deriving preliminary sediment cleanup goals for chemicals that are present in fish tissue at concentrations associated with unacceptable risk. If the relationship cannot be established, then alternate methods for developing sediment cleanup goals will be required.

The process described above is applicable to the entire RI/FS project. However, before any food web model can be used to assist in cleanup decisions, the model should be selected, parameterized, and tested in an iterative fashion. This memorandum describes the evaluation of several existing food web models using available site-specific data. Food web models may be used for multiple organic chemicals, but only total polychlorinated biphenyls (PCBs) as Aroclors were evaluated in this memorandum because they are likely to be one of the primary risk drivers, and much of the previous model validation effort in the scientific literature has been based on PCBs. The candidate models must perform adequately for PCB data if they are to be selected for use in this project. If the baseline risk assessments suggest that preliminary sediment cleanup goals are appropriate for additional chemicals, modeling of additional chemicals may be conducted later. A food web model that performed adequately for PCBs would presumably also be suitable for many other hydrophobic nonionic chemicals with similar partitioning behavior.

The objectives of this memorandum are to:

- evaluate the ability of existing food web models to predict PCB concentrations in resident Lower Willamette River (LWR) fish species to be evaluated in the ecological and human health risk assessments
- based on a comparison of model performance, select a food web model for use in subsequent phases of the RI/FS to assess PCBs
- conduct sensitivity and uncertainty analyses on model input parameters to identify data gaps that should be filled

1.2 MODELING FRAMEWORK

Environmental models can generally be grouped into two categories: steady-state or dynamic. In a steady-state model, relationships between variables in model compartments are constant. In a dynamic model, these relationships are allowed to vary over time. Deciding whether to use a steady-state or dynamic model depends on several factors, the most important of which is the temporal variability of the variables being modeled. For this memorandum, the modeled variable is PCB concentrations in fish tissue. PCBs are extremely stable compounds, and slow to chemically degrade under environmental conditions (Eisler 1986). Consequently, because steady-state models are generally simpler to run than dynamic models, and PCB concentrations in the environment are expected to be slow to change over time, only steady-state models are evaluated in this memorandum. The potential utility of a dynamic food web model will be discussed with the US Environmental Protection Agency (EPA) and its partners once they have reviewed this memorandum.

The technical approach used to evaluate the steady-state models described in this memorandum relies on limited site-specific data for PCB concentrations in sediment and water. Although much is known about the LWR chemical and physical environment, there are still data gaps that may impair the predictive ability of the models being evaluated. Some of these data gaps will be filled during upcoming sampling associated with the RI/FS (i.e., proposed Round 2 sampling). The evaluation and selection of the appropriate food web model for the Portland Harbor RI/FS is an iterative process. The modeling described in this memorandum is the first step in the process, but subsequent steps will be necessary before a model can be used for decision-making in the RI/FS. The subsequent steps will include, at a minimum, additional model runs following collection of more site-specific data during the Round 2 data collection activities. Calibration and validation may also be conducted as part of the additional model runs.

2.0 BRIEF DESCRIPTION OF CANDIDATE MODELS

Many steady-state food web models have been developed and published in the past 20 years. Several models stand out because they have been applied and calibrated to several aquatic systems and because they are widely cited by scientists conducting food web model research. These include models developed by Thomann et al. (1992), Gobas (1993), Campfens and MacKay (1997), Arnot and Gobas (in press), and the US Army Corps of Engineers (TrophicTrace) (USACE 2003). These models were evaluated for potential application to the Portland Harbor ecosystem. Biota-sediment accumulation factors (BSAFs), an alternative to modeling, were also investigated. The technical framework and previous applications (particularly for environments similar to Portland Harbor) of each candidate model and BSAFs are briefly summarized below.

2.1 BIOTA-SEDIMENT ACCUMULATION FACTOR (BSAF)

A simple alternative to food web modeling is to estimate chemical concentrations in biota using biota-sediment accumulation factors (BSAFs). A BSAF is the ratio of a chemical concentration in tissue to the chemical concentration in sediment. For organic chemicals, tissue concentrations are typically lipid-normalized, and sediment concentrations are typically organic carbon (OC)-normalized.

2.1.1 Technical Framework

The simplest application of BSAFs depends on the assumption that the concentration of chemicals in organisms is a linear no-threshold function of the concentration in sediment (ORNL 1998). This assumption does not usually hold for chemicals that are metabolized or otherwise regulated by the organism, such as polycyclic aromatic hydrocarbons or some metals, but for chemicals that are largely not regulated, such as PCBs, the assumption may hold, at least over a finite concentration range. A nonlinear relationship may also be observed in some cases. For example BSAFs for some dioxin and furan congeners exhibited significant nonlinear variations with Dungeness crab (*Cancer magister*) or sediment concentrations (Cretney and Yunker 2000).

2.1.2 Previous Applications of the Model

BSAFs have historically been used to predict chemical concentrations in benthic invertebrate tissue based on chemical concentrations in sediment, with mixed success. BSAFs for PCBs have been estimated for a variety of freshwater invertebrate species, including oligochaetes, mayfly, caddisfly, crayfish, and amphipods (Ankley et al. 1992; Drouillard et al. 1996; Morrison et al. 1996; Oliver 1987). Predicting fish tissue concentrations from sediment concentrations using this method is theoretically unreliable for large sites with variable sediment chemistry because fish, being mobile, may be exposed to variable sediment concentrations. If a predictive relationship between fish or invertebrates and sediment concentrations could be derived, it would theoretically be strongest for species that are closely linked to sediments through habitat and dietary composition, and that also have small home ranges.

2.2 THOMANN ET AL. (1992)

The Thomann et al. (1992) food web model is a five-compartment, mechanistic, chemical mass-balance model that was designed to improve upon an earlier Thomann (1989) version. The five compartments are phytoplankton/detritus, zooplankton, benthic invertebrates, forage fish, and piscivorous fish. All compartments, including phytoplankton, contain loss mechanisms such as growth and excretion. The 1992 version provided a more accurate method of linking sediment to an aquatic food web than the frequently applied simple partitioning method. An executable version of this model was not available. Due to the difficulty of obtaining many of the equations and parameters from field-collected data or the literature, this model was not selected for further evaluation.

2.3 CAMPFENS AND MACKAY (1997) FUGACITY MODEL

This model describes bioaccumulation in a food web consisting of chemical uptake from diet, sediment porewater, and the water column. The thermodynamic model expressions are formulated using the fugacity concept. Fugacity is the chemical potential or escaping tendency of a chemical from a particular phase (e.g., water, air) in units of pressure. Fugacity can be related to concentration by a fugacity capacity constant or Z factor. The convenience of a fugacity-based food web model is that the user can estimate fugacity at any section of a food web using a single algorithm, and then determine concentration from that fugacity. This model, therefore, has a potentially unlimited number of compartments.

2.3.1 Technical Framework

Campfens and MacKay built the fugacity model from the early bioaccumulation models of Thomann (1989) and Thomann et al. (1992), which lacked sediment components. As a result, the Campfens and MacKay model assumes the same uptake and loss processes of the previously described Thomann models, with the exception that sediment exposure can only be modeled through the diet pathway for the Campfens and MacKay model.

A fugacity model works by calculating partial fugacities for each phase that contributes to bioaccumulation of the chemical in an organism, and then summing them to determine total fugacity. Concentrations are calculated from corresponding fugacities. Chemical concentrations for phytoplankton are calculated assuming they are in, or approaching, equilibrium with chemical concentrations in the water column. Chemical concentrations for zooplankton, filter feeders, and benthic detritivores are calculated assuming uptake from water and sediment porewater via respiration and diet. Fish chemical concentrations are calculated assuming uptake from water via gill ventilation and diet. Loss of chemical for zooplankton, filter feeders, and fish are calculated assuming losses due to respiration, egestion, metabolism, and growth.

2.3.2. Previous Applications of the Model

The Campfens and MacKay (1997) model has been applied in a number of environments. Modified versions of the model have been used to test PCB loading hypotheses for Lake Ellasjøen in Norway (Gandhi et al. 2004) and to investigate biomagnification and metabolism of PCBs in the Barents Sea (Fraser et al. 2002). For Lake Ellasjøen, model estimates of chemical concentrations in fish compared well with measured concentrations. The Barents Sea model was used to estimate BAFs and metabolic half lives for different chemicals and was not used for predicting chemical concentrations in biota. Sarah Gewurtz, a PhD candidate in the Department of Geography at the University of Toronto in Canada, is in the process of applying a general food web model, based on the models of Campfens and MacKay (1997) and Morrison et al. (1997), to improve understanding of the mechanisms controlling the accumulation of persistent organic pollutants (POPs) and mercury in aquatic biota in Lakes Winnipeg and Laberge in Canada and Lakes Ellasjøen and Øyangen in Norway (Gewurtz 2004).

2.4 GOBAS MODEL WITH ARNOT UPDATES (ARNOT AND GOBAS IN PRESS)

The original Gobas (1993) model is a four-compartment, steady-state, mass-balance model. The four compartments are phytoplankton/macrophytes, zooplankton, benthic invertebrates, and fish. In 2004, Arnot and Gobas (in press) applied a newly updated version of the Gobas model to three of the Great Lakes and compared the results with the original Gobas model outcomes. New elements added to the model by Arnot include 1) a new model for partitioning chemicals into organisms; 2) kinetic models for predicting chemical concentrations in algae, phytoplankton, and zooplankton; 3) new allometric relationships for predicting gill ventilation rates in a wide range of aquatic species; and 4) the inclusion of a mechanistic model for predicting gastrointestinal magnification[1] of organic chemicals in a range of species. The new model is intended to provide better estimates of BSAFs. Windward acquired and evaluated an Excel® version of this new model from the author (Arnot). The updated Arnot and Gobas model also provides output using the original Gobas (1993) model, so the original Gobas model was also evaluated with those results.

[1] Gastrointestinal magnification is the process by which a chemical's concentration in the ingested tissue fraction increases as it passes through the gut, due to digestion and absorption of the chyme relative to the slow uptake of the chemical. This results in a greater concentration gradient between the organism and its food, and can partially explain the mechanism of biomagnification up the food chain.

2.4.1 Technical Framework

Chemical concentrations in phytoplankton are calculated assuming equilibrium partitioning of the chemical between the water column and the lipids and OC of the phytoplankton based on the octanol-water partition coefficient (K_{OW}) of the chemical. Chemical concentrations in zooplankton, invertebrates, and fish are calculated assuming uptake from water via the gills and uptake from the diet. Losses for zooplankton, invertebrates, and fish include metabolism, growth dilution, loss to water via gills, and fecal egestion. Chemical concentrations in filter-feeding invertebrates are calculated assuming uptake via ingestion of plankton and suspended solids, and uptake from water via the respiratory surface. Filter-feeders are linked to sediments via ingestion of suspended sediments.

2.4.2 Previous Applications of the Model

The Gobas model has been used in a broad range of environments. The Gobas model (1993) has gained general scientific acceptance and is now being used in scientific and regulatory applications to predict concentrations of hydrophobic organic contaminants in aquatic food webs. The original model, when applied to Lake Ontario, predicted tissue concentrations, on average, within a factor of 1.8 (Gobas 1993). Burkhard (1998) reviewed the predictive capabilities of Gobas (1993) and Thomann et al. (1992), as compared to field-collected fish data from Lake Ontario, and concluded that the Gobas model provided slightly better predictions. In 1997, Morrison et al. (1997) applied an updated version of the Gobas model to PCBs in Lake Erie. Ninety-five percent of observed concentrations in invertebrates and fish were within a factor of 2 of predicted concentrations. In 2002, a modified version of the 1993 model was used to model the bioaccumulation dynamics of hydrophobic organic contaminants in the Anacostia River (Foster et al. 2002). In 2003, an updated version of the Gobas model was applied to PCBs in San Francisco Bay (Gobas and Wilcockson 2003). Observed concentrations for two polychaete species and two fish species were within factors of 1.6 and 1.1, respectively, of predicted concentrations. The modifications developed by Arnot were applied to previously collected data from three Great Lakes (Arnot and Gobas in press). Sixty and ninety percent of the Arnot and Gobas model-predicted Bioaccumulation Factors (BAFs) for fish were within a factor of 2 and 10 of the empirical BAFs, respectively, compared to 19% and 71% for the original Gobas model.

2.5 TROPHICTRACE (USACE 2003)

TrophicTrace is an Excel® spreadsheet model that estimates concentrations in invertebrates and fish for a user-specified food web. Chemical concentrations in specific invertebrate prey species are assumed to be derived either entirely from sediment or entirely from water, depending on whether the user designates the invertebrate species as a deposit feeder or filter feeder, respectively.

2.5.1 Technical Framework

Chemical concentrations in fish tissue are calculated using a steady-state model based on the approach of Gobas (1993) and Gobas et al. (1995). Values for the rate constants are calculated using equations from several sources (Burkhard 1998, Gobas 1993, Gobas et al. 1995). Chemical concentrations in invertebrates are predicted using a user-specified BSAF. Users can characterize uncertainty using trapezoidal fuzzy numbers (e.g., a minimum, a range of likeliest values, and a maximum). The uncertainties are propagated throughout the analysis using fuzzy arithmetic principles, and are also presented as trapezoidal fuzzy numbers. To simplify the comparability of the results from this model to the results from the other models, which do not have probabilistic capabilities, the probabilistic capabilities of this model were not applied during the model runs described in this memorandum.

2.5.2 Previous Applications of the Model

TrophicTrace was developed specifically for the United States Army Corps of Engineers (USACE) to use in their dredged material management program for sediment disposal decisions. An example data set for the New York/New Jersey harbor was provided with the model software. Although the model is being used at sites currently being evaluated (e.g., a proposed dredging project in the Mississippi Delta on the Sunflower River), none of the results appear to have been published at this time.

3.0 METHODS

The candidate models were run using the following process:

- Step 1 – establish fish species to be modeled (Section 3.1.1)
- Step 2 – compile existing model input data from site-specific (Section 3.1.2) and literature (Section 3.1.3) sources
- Step 3 – derive multiple food webs for testing (Section 3.1.4)
- Step 4 – develop multiple model scenarios based on combinations of input data and food webs (Section 3.2)
- Step 5 – run each model scenario and compare to PCB concentrations for Round 1 fish samples (Section 3.3)
- Step 6 – conduct sensitivity and uncertainty analyses (Section 3.4)

3.1 MODEL SETUP / PARAMETERIZATION

Existing data were compiled for entry into each model. To the extent possible, identical values were used for variables common to multiple models to increase the comparability between models. The sources and data reduction methods for the input data, food webs, and model scenarios are described in the following sections.

3.1.1 Selected Fish Species

Tissue concentrations are available from Round 1 for eight resident fish species representative of various feeding guilds in the LWR:

- **Omnivores/herbivores:** largescale sucker (*Catostomus macrocheilus*), carp (*Cyprinus carpio*), and brown bullhead (*Ameiurus nebulosus*)
- **Invertivores:** sculpin (*Cottus* spp.) and peamouth (*Mylocheilus caurinus*)
- **Piscivores:** smallmouth bass (*Micropterus dolomieui*), northern pikeminnow (*Ptychocheilus oregonensis*), and black crappie (*Pomoxis nigromaculatus*)

Resident species are appropriate for use in the food web models because a steady-state condition may exist between chemical concentrations in Portland Harbor sediment and chemical concentrations in the tissue. Such a relationship is unlikely to exist between the sediment and chemicals concentration in tissue of anadromous and wide-ranging fish with relatively short residence times in the LWR, especially adult fish. Juvenile salmonids may remain in the harbor long enough to reach a near steady-state condition, but resident fish that remain in the LWR throughout their lives should be an acceptable surrogate for juvenile salmonids.

The candidate models were run under various scenarios for these eight fish species, except for the BSAF model. The BSAF model is only applicable to sculpin and crayfish (also collected from the Site in Round 1), as co-located tissue and sediment PCB concentrations are needed and are only available for these two species. The output of the candidate food web models will be predicted total PCB concentrations in each of these eight fish species.

Composite samples of whole-body fish and crayfish were collected in Round 1 sampling and analyzed for various chemicals, including PCB Aroclors. These data were used to evaluate the predictive power of the candidate models, as described in Section 4.0.

Total PCBs (as Aroclors) were calculated for each composite sample using the following rules:

- For composite samples with one or more detected Aroclor, the sum of the detected concentrations represented the total PCB Aroclor concentration
- For composite samples with no detected Aroclors, the highest individual Aroclor detection limit (DL) represented the total PCB Aroclor concentration and the sample was qualified as ND (not detected)[2]

Summary statistics for total PCB Aroclor concentrations, including arithmetic mean, geometric mean, median, and maximum, were calculated for each of these species (Table 3-1). The number of composite samples varied by species, ranging from 4 to 26. The collection locations for the resident fish species are shown in Figure 3-1.

3.1.2 Input Parameters from Available Portland Harbor Data Sets

PCB concentrations in surface sediment (0-15 cm), prey tissue, and surface water were derived from available site-specific data sets. Both historical and Round 1 PCB Aroclor data were used. The historical data set was developed for Portland Harbor as part of the Portland Harbor RI/FS Programmatic Work Plan (Integral et al. 2004). The historical data set includes all Category 1[3] surface sediment and surface water data collected within the Portland Harbor Superfund Site since 1990. Round 1 sampling events in the Portland Harbor Initial Study Area (ISA) were conducted in the summer

[2] In Round 1 fish tissue, all composite samples had at least one detected Aroclor. Therefore, no composite samples were qualified as ND.
[3] The quality of historical data sets was evaluated prior to considering their use in the RI. Data qualified as Category 1 had acceptable and documented data quality criteria (i.e., traceability, comparability, sample integrity, potential measurement bias, accuracy, and precision) and were considered acceptable for use.

and fall of 2002 and included the collection of surface sediment and whole-body tissue from selected fish and invertebrate species.

Total PCB concentrations in sediment
The total PCB sediment concentration that was input into the candidate models was derived from both historical (Category 1) and Round 1 data. PCB Aroclor data from 240 historical sediment samples from within the study area being addressed in the RI/FS, and 53 Round 1 sediment samples were included in the data set (Figure 3-2). Total PCBs (as Aroclors) were calculated for each sampling location using the same rules listed in Section 3.1.1 for tissue.

These data were then analyzed in the geographic information system (GIS) to generate an area-weighted average (AWA) concentration using the inverse distance weighting (IDW) method. IDW interpolation is a spatial calculation that predicts values for locations where chemical concentrations were not measured. IDW interpolation is based on the assumption that sediment concentrations that are close to one another are more alike than those that are farther apart. Therefore, a location without a known sediment concentration can be estimated by weighting the nearby sediment concentrations according to their distance from the location without a known sediment concentration and then calculating an IDW interpolation.

For samples qualified as ND, one-half the total PCB Aroclor ND concentration was used to represent the concentration at the respective location. The sediment concentration derived from the IDW method (i.e., 509 µg/kg dw) was used as the input value for sediment concentration in all the models.

Total PCB concentrations in prey species
During Round 1, PCB concentrations were measured in crayfish (*Pacifastacus* spp.), clams (*Corbicula fluminea*), and juvenile chinook salmon (*Oncorhynchus tshawytscha*), in addition to the fish species listed in Section 3.1.1. These species are prey items for several of the resident fish species described in Section 3.1.1. Summary statistics for these species are given in Table 3-1.

Total PCB concentrations in surface water
Total PCBs have never been detected in whole-water samples collected from Portland Harbor (Integral et al. 2004). However, semipermeable membrane devices (SPMDs) were deployed in 1997 and 1998 within the Portland Harbor study area during a United States Geological Survey (USGS) study (McCarthy and Gale 1999). During low-flow conditions, the dissolved concentration of all quantified ortho-substituted PCB congeners in surface water was estimated to be 2 ng/L, based on the SPMD data. Because of the large number of PCB congeners that were detected (>110), this number was used as a surrogate for total PCBs. Five non-ortho-substituted PCB congeners were also quantified, but the total estimated dissolved concentration for these five congeners was only 0.01 ng/L, so no adjustment to the 2 ng/L total was deemed necessary.

The TrophicTrace model was also used as a source for total PCBs in surface water. This model can predict a concentration dissolved in water using equilibrium partitioning theory and a user-defined sediment concentration. A total surface water PCB concentration of 21 ng/L was generated using the AWA sediment PCB concentration of 509 µg/kg dw. The factor of 10 discrepancy between the water concentration of PCBs estimated from the SPMD data (2 ng/L) and that predicted by TrophicTrace (21 ng/L) suggests that the concentration derived from equilibrium partitioning is a theoretical maximum concentration that may never be reached in a dynamic river system where water concentrations are not at equilibrium with the PCB concentrations in the underlying sediment.

Physical input parameters

Data for physical parameters reported in the historical and /or the Round 1 database were used as input in the candidate models. These parameters include fish and invertebrate body weights and percent lipid (Table 3-1), water temperature, percent solids, and percent OC in sediment. The selected input data for these and other environmental parameters used in the models are presented in Table 3-2. Data for all other input parameters used in the models were derived from literature sources, as described in Section 3.1.3.

3.1.3 Input Parameters from Technical Literature

Several parameters associated with total PCBs were derived from the technical literature. Two total PCB molecular weights were used (326, as used by Campfens and MacKay 1997; 250.5, as used by Arnot and Gobas in press) because they were default values referenced in the respective papers. The Henry's Law constant for total PCBs, which was used for the Campfens and MacKay model, was another default obtained from Campfens and MacKay (1997). The metabolism half-life for the predicted PCB concentration (5,000 days) was taken from Campfens and MacKay (1997). Two total PCB K_{OW}s (hereafter expressed as the base 10 logarithm of the K_{OW}) were evaluated. A K_{OW} of 7.3 (MacKay et al. 1992) was used because it was the default given for total PCBs in the TrophicTrace model. A lower K_{OW} of 6.3 was estimated using EPA's Estimated Program Interface (EPI) software suite (version 3.11).[4] EPI is a Windows®-based suite of physical/chemical property and environmental fate estimation models developed by EPA's Office of Pollution Prevention Toxics and Syracuse Research Corporation.

Total PCB BSAF values of 0.87 (for field-collected oligochaetes; Ankley et al. 1992) and 1.43 (for crayfish collected from the Round 1 study area; see Section 4.1) were used to predict total PCB concentrations in the TrophicTrace model. In addition, a BSAF value of 1 was used for food webs 2 and 5 (see Section 3.1.4) in the TrophicTrace model, which included sediment as a dietary item.[5] The other food web

[4] Available from http://www.epa.gov/opptintr/exposure/docs/episuite.htm
[5] TrophicTrace does not explicitly allow the ingestion of sediment by fish species. However, by assuming a BSAF of 1 (i.e., TOC and lipid are equivalent), sediment can be assigned as a "prey" item in the model.

models do not need a BSAF as an input parameter; the relationship between sediment and tissue is calculated within the models.

Table 3-2 displays the chemical, environmental, and food web input parameters derived from the technical literature for each model. Not all input parameters used in the four food web models are shown in this table. Additional parameter values needed for the Campfens and MacKay model, such as digestion factor, growth rate as a fraction of volume per day, feeding rate as a percent of body mass per day, and water and organic gut absorption efficiency, were taken from defaults provided by Campfens and MacKay (1997). Default values for many input parameters were also taken from the Gobas (1993), Arnot and Gobas (in press), and TrophicTrace (USACE 2003) models for use in those models.

3.1.4 Explanation and Justification of Food Webs

Six food webs for the LWR were developed using the historical and Round 1 data and available literature. Each food web consists of prey items for each of the eight resident fish species and the fraction of the total diet represented by those prey items. The sum of all the fractional components of the diet for each fish species equals one. Some of the food webs also include sediment ingestion. The dietary composition differs for each fish species. Some fish species consume only invertebrates, or invertebrates and sediment, while other fish species consume both invertebrates and fish. Fish and invertebrate prey species for each fish species were determined from stomach-content analyses presented in Appendix B of the Portland Harbor RI/FS Programmatic Work Plan (Integral et al. 2004). Dietary preferences were calculated from other scientific literature obtained from FishBase, an electronic database available at www.fishbase.org.

Sediment ingestion rates used in the models are cited in the Portland Harbor Ecological Risk Assessment Approach for the Preliminary Risk Evaluation for Ecological Receptors (Windward 2004). Food webs do not include intra-species predation and predation of fish placed in a higher trophic level. Although literature suggests that both types of predation do occur, the models could not be executed for species for which output was being calculated with a circular reference (i.e. assumed to eat members of its own species or their own predators).

Food web 1

Food web 1 dietary intakes are based on the available historical and Round 1 invertebrate prey species data, which are limited to clam and crayfish (Table 3-3). No other invertebrate species were included in this diet. Clam and crayfish diets were divided between the possible options of phytoplankton, zooplankton, and clam (for crayfish) based on available literature (Table 3-4). Zooplankton were included as a biota compartment for only the Gobas and the Arnot and Gobas models. For each fish species, no single prey item was preferred over any other prey item (Table 3-3). For example, peamouth were assumed be equally likely to eat juvenile chinook salmon, sculpin, clams, or crayfish, so each prey item was given a diet fraction of 0.25. Sediment was not included as a dietary item.

Food web 2

As with food web 1, dietary intakes for food web 2 are based on the assumption that all prey items were preferred equally (Table 3-5). However, five additional invertebrate groups and sediment were added to the clam and crayfish compartments referenced in food web 1. The five additional invertebrate groups, which are based on the stomach-content analyses for fish caught in Portland Harbor (Integral et al. 2004), include worms (roundworm/oligochaete), aquatic insects (wasp, dipterans, chironomid), amphipods/isopods, bryozoans (*Cristatalla mucedo*), and gastropods (snail, *Physa* spp. and limpet, *Fisherola* spp.). Invertebrate diets are based on reported preferences from available literature (Table 3-4).

Food web 3

As with food webs 1 and 2, dietary intakes for food web 3 are based on the assumption that all prey items were preferred equally (Table 3-6). This food web is identical to food web 2 except that sediment was not included as a dietary item.

Food web 4

Food web 4 dietary intakes are based on reported preferences from available literature for each fish species (Table 3-7). The best literature reference was selected based on its applicability to the Portland Harbor environment and its inclusiveness of the selected fish and invertebrates. Clam and crayfish were the only invertebrates included for this food web, and sediment was not included as a dietary item. For black crappie, the best literature reference for smallmouth bass (a fish in the same family) was used because a best literature reference for black crappie was not available. For juvenile chinook salmon, when the best literature did not report preferences for specific fish or when there was no best literature reference for the entire family, diet fractions were distributed equally among the same compartments used in food webs 1, 2, and 3.

Food web 5

Food web 5 dietary intakes are based on reported preferences from available literature for each fish species (Table 3-8). Food web 5 differs from food web 4 in that five additional invertebrate groups (the same groups used in food webs 2 and 3), phytoplankton and sediment were added to the clam and crayfish compartments used in food web 4. The same best literature references used in food web 4 were used for food web 5.

Food web 6

Food web 6 dietary intakes are based on reported preferences from available literature for each fish species (Table 3-9). This food web is identical to food web 5 except that sediment was not included as a dietary item.

There are some differences between food web matrices for the food web models and those proposed in the draft Ecological Risk Assessment (ERA) Technical Memorandum Comprehensive Synopsis of Approaches and Methods, to be submitted to EPA on June 25, 2004. "Best literature" sources for species dietary preferences in the draft ERA matrices were chosen based on location within or near the ISA, while the one "best literature" source for species dietary preferences in the food web model matrices was chosen based on its applicability to the Portland Harbor environment and its inclusiveness of the selected fish and invertebrates. Dietary matrices for the food web model were created excluding cannibalism as this was a limitation for three of the four models, while cannibalism was included for draft ERA matrices. Additionally, sediment ingestion fractions in food web model matrices for black crappie, brown bullhead, and carp were based on comparisons to fish in equivalent feeding guilds, gut content analysis, and best professional judgment. For the food web models, the various dietary matrices serve as different scenarios for comparing the models and testing the feasibility of using a food web model to guide the ERA and cleanup goals, thus the matrices are exploratory at this time.

3.2 MODEL SCENARIOS

Model scenarios were developed from unique combinations of the six food webs, two K_{OW}s for total PCBs, two PCB concentrations in surface water, and three BSAFs. Table 3-10 summarizes the model scenarios. Only a subset of the model scenarios listed in Table 3-10 were run in each model, depending on specific model configurations and limitations. The scenarios run in each model are described in detail below.

3.2.1 Arnot and Gobas Model Scenarios

Twenty-four scenarios were run for the Arnot and Gobas model and the Gobas model. The scenarios consisted of combinations of the six food webs (see Section 3.1.2 for explanations of the food webs), two K_{OW} values, and two PCB water concentrations (Table 3-10). Food webs 1, 3, 4, and 6 were tested for scenarios i through l, and food webs 2 and 5 were tested for scenarios e through h. BSAFs and invertebrate dietary pathway are not inputs to these models and so they were not used. For the Arnot and Gobas model, invertebrate concentrations are calculated based on uptake from the diet, water, and sediment.

Certain food webs had to be altered to be compatible with the model structure. The Arnot and Gobas model would not allow cannibalism or the consumption of prey species that are normally predators at a higher level in the food chain. Both stomach-content analyses and literature sources indicated that these feeding habits were prevalent for some of the resident fish species. When any of these feeding habits were indicated for the best literature reference, it was eliminated from the food web, and its fraction of the diet was divided evenly among the remaining prey items. The Arnot and Gobas model would only accommodate five invertebrate compartments. Seven invertebrate groups were selected for the food web dietary intakes for food webs not limited to invertebrate compartments of clam and crayfish only (Section 3.1.4). To reduce the number of invertebrates, gastropod and clam were combined into one biota compartment "mollusk," and bryozoans were combined with zooplankton. Lipid concentrations and weights of each were averaged to derive the new lipid and weight values for the two revised compartments. Additional changes to each food web are discussed below.

For food webs 2 and 3, northern pikeminnow was eliminated from the diet of smallmouth bass, and sculpin was eliminated from the diet of crayfish. Both are examples of eating higher on the food chain. This was an unrealistic assumption as the literature indicated the presence of these species in the gut contents of those fish. This could have had significant effects on model output. It may be useful to create additional size classes of fish to allow these dietary intakes.

For food web 4, northern pikeminnow was eliminated from the diets of black crappie and smallmouth bass, and northern pikeminnow and smallmouth bass were eliminated from the diet of brown bullhead. These are also examples of eating higher on the food chain.

For food webs 5 and 6, northern pikeminnow was eliminated from the diets of black crappie and smallmouth bass, and northern pikeminnow and smallmouth bass were eliminated from the diet of brown bullhead. Sculpin were also eliminated from the crayfish diet.

3.2.2 Campfens and MacKay Model Scenarios

Due to the limitations of the fugacity model application, only eight scenarios were run, based on food webs 1 and 4 (Table 3-10). Campfens and MacKay's DOS-based Basic® model was developed to predict PCB concentrations for a total of only nine species; it could thus not fully capture the Portland Harbor ecosystem with all invertebrates included. Sediment was not included as a dietary component. Default values were selected from surrogate species that shared similar taxonomy, ecology, or biological similarities. For example, crayfish parameters were assumed to be the same as mysids, which were included as a default species in the original model. Input parameters for brown bullhead and largescale sucker were set equal to default parameters given for sculpin by Campfens and MacKay (1997). For carp, northern pikeminnow, and peamouth, the default parameters provided for bluntnose minnow were used because all these species are in the cyprinid family. Finally, input parameters for black crappie were set equal to default parameters provided for smallmouth bass (Campfens and MacKay modified 1998). Additional changes to each food web are discussed below.

For food webs 1 and 4, crayfish and clam were combined into one prey compartment, and the crayfish weight and percent lipid content were used to run the model due to the limitations on the number of dietary compartments that could be included. All fish were assumed to be eating crayfish even though some predators may consume clams. Peamouth was eliminated as a receptor and prey item because the model could not incorporate it due to limitations on the number of dietary compartments. The dietary preferences for northern pikeminnow and smallmouth bass were recalculated for the remaining dietary prey species to 14.3% and 20%, respectively.

For food web 4, carp and peamouth were combined into one compartment because they are in the same family (Cyprinidae) and have a similar diet. The weight and percent lipid content for carp were used to run the model. All fish that consumed peamouth were assumed to eat carp instead.

3.2.3 TrophicTrace Model Scenarios

All six food webs were tested with the TrophicTrace model using 40 different model scenarios. Food webs 1, 3, 4, and 6 were tested for scenarios a through h, and food webs 2 and 5 were tested for scenarios a through d. The food webs were executed for two K_{OW} values, two PCB concentrations in waters, and three BSAFs. Each scenario assumed that invertebrates were either sediment-based (i.e., consistently exposed to sediment) or water-based (i.e., in the water column or on structures above the river bottom). Clams, crayfish, worms, amphipods, and gastropods were assumed to be sediment-based. Insects, bryozoans, and phytoplankton were assumed to be water-based.

Due to the limitations of the model's ability to accept more than ten dietary items and to account for direct sediment ingestion, several alterations were made to some of the food webs presented in Section 3.1.2, as described below.

For food web 2, to predict the total PCB concentration for northern pikeminnow, the crayfish and amphipod compartments were combined because both had the same lipid percentage. The black crappie and smallmouth bass compartments were also combined because they had the same dietary preferences and similar lipid percentages. To predict the total PCB concentration for smallmouth bass, the crayfish and insect compartments were combined because they had the most similar lipid percentage from the available dietary invertebrates.

For food web 3, to predict the total PCB concentration for northern pikeminnow, smallmouth bass was eliminated as a dietary item. Because smallmouth bass had a dietary preference for northern pikeminnow, a circular reference was created, which the TrophicTrace model could not calculate. Therefore, the dietary preferences were reset to 10% for each of the ten remaining dietary items.

For food web 5, to predict the total PCB concentration for brown bullhead, the crayfish, amphipod, and insect compartments were combined because the crayfish and amphipod compartments have the same lipid percentage, which is similar to the lipid percentage for insects.

For food webs 2 and 5, sediment was compartmentalized as an invertebrate dietary item to account for the direct ingestion of sediment by fish. In order to accomplish this, the lipid percentage for the sediment compartment was given the same value as the total organic carbon (TOC) percentage in sediment. Furthermore, both food webs were executed using a BSAF of 1, which was applied to the prediction for the entire model scenario.

For food web 6, to predict total PCB concentration for brown bullhead, the crayfish and amphipod compartments were combined because both had the same lipid percentage. The black crappie and smallmouth bass compartments were also combined because they had the same dietary preferences and similar lipid percentages.

3.3 MODEL RUNS

To compare the outcome of each model scenario, the predicted and measured concentrations of each fish were compared by calculating the relative percent difference (RPD). Because of the small amount of data available for many of the resident species being modeled, the results of several types of calculations (i.e., mean, median, geometric mean, and maximum) on the measured data were compared to the predicted concentrations. With a small number of data points, the arithmetic mean can be greatly skewed if outlier concentrations exist. Mean and median RPDs across all species for a given scenario were summarized. The number of RPDs for a given model scenario that were less than 100% (i.e., a factor of 2) and 400% (i.e., a factor of 5) were also summarized. Past reported model outputs have been compared to a factor of 2 by Campfens and MacKay (1997), Gobas (1993) and Arnot and Gobas (in press). A factor of 5 was also chosen to provide additional perspective on the model output.

3.4 SENSITIVITY ANALYSIS / UNCERTAINTY ANALYSIS

Sensitivity and uncertainty analyses are related yet distinct analyses that were applied to the best-performing model scenarios described above. Sensitivity analysis involves altering a single input parameter by a fixed amount and determining how the output is related to that change. For the sensitivity analysis summarized in Section 4, key input parameters were altered by 10%. Output will be readily influenced by sensitive parameters and not influenced by insensitive parameters.

Alternate values for key parameters can also be explored during uncertainty analysis, but the alternate values selected were limited to those that might plausibly occur in Portland Harbor. The uncertainty analysis also includes a discussion of the confidence in the input data. The variables evaluated in the uncertainty and sensitivity analyses, and the manner in which they were changed, are shown in Tables 3-11, 3-12, and 3-13.

4.0 RESULTS AND DISCUSSION

4.1 BSAF

Site-specific BSAFs were evaluated for sculpin and crayfish because co-located sediment and tissue PCB concentrations were collected during Round 1 for these two species. Total PCB concentrations (lipid-normalized) in both species were positively correlated with total PCB concentrations in co-located sediment samples (OC-normalized) (Table 4-1), although the correlation was very weak for crayfish (correlation coefficient of 0.064). The mean BSAFs were 2.36 for sculpin and 1.20 for crayfish.

The correlation coefficient for sculpin (0.80) indicates that the relationship between PCB concentrations in tissue and sediment was consistent throughout the range of PCB concentrations observed. Total PCB concentrations in crayfish tissue did not vary greatly; most concentrations were between 2 and 10 mg/kg lipid. For crayfish, the calculated BSAFs appear to be distributed in two modes based on the wide range of total PCB concentrations in the co-located sediment. Approximately half the concentrations were above 30 mg/kg OC (maximum of 217 mg/kg OC), while the rest of the concentrations were between 1 and 7 mg/kg OC. The correlation coefficient between PCB concentrations in tissue and sediment was low (-0.12) for the samples with higher PCB concentrations, but the correlation was much better for the lower PCB concentration group (0.86). These results suggest that one of the fundamental assumptions for the simplest use of BSAFs, that a linear relationship exists across the observed range of chemical concentrations, was violated for crayfish. A non-linear relationship may exist over some or all of the observed concentrations, but no additional statistical analysis was conducted because the crayfish BSAFs varied so widely. These data do not provide enough understanding to determine whether or not sediment concentration is the primary risk driver for crayfish accumulation of PCBs. A lack of relationship between co-located samples for tissue and sediment concentrations could have more to do with crayfish behavior (home-range) or metabolism than route of chemical uptake.

Due to the fact that BSAFs were generated using measured data from the ISA, no uncertainty analysis was conducted for this model, although uncertainty does exist. Model assumptions and parameters with uncertainty are crayfish behavior and movements, and major paths of chemical transfer. Uncertainty for other models is discussed in Sections 4.3-4.5. Because of the linear nature of the equation used to calculate BSAFs, any increase in an input parameter would have a proportional effect on the output, and thus no sensitivity analysis was conducted for this model.

4.2 CAMPFENS AND MACKAY

A total of eight scenarios were executed for the Campfens and MacKay fugacity model. Overall, scenario 1k, with a K_{OW} of 6.3 and observed total PCB concentration in water of 2 ng/L, produced the best results (Table 4-2). This scenario predicted the total PCB concentration in two of the fish species within a factor of five compared to the measured tissue concentration. Scenario 4k predicted total PCB concentration in one of the eight fish species within a factor of two, and two of the eight fish species within a factor of five compared to the measured tissue concentration. Scenario 1k barely outperformed scenario 4k, based on the mean and median RPDs.

A majority of the predicted total PCB concentrations for each fish species were much higher (by factors of 100 to >100,000) than the measured concentrations. The complete results for the modeled scenarios are presented in Appendix A. The fugacity model is limited to fewer prey components than the number found in the Portland Harbor ecosystem, and is therefore incompatible with the environment being modeled. This model does not completely capture the food web modeling scenarios as they have been developed. Based on the poor performance of this model relative to the other food web models (see Sections 4.3, 4.4, and 4.5), and the limitations in model structure with regard to the number of compartments that can be modeled, no further analyses (i.e., sensitivity and uncertainty) were conducted for this model.

4.3 GOBAS MODEL

4.3.1 Scenario Results

For the Gobas model the scenario that produced the best results was 3k (no preference diet with no sediment food web, K_{OW} 6.3 and PCB water concentration of 2 ng/L) (Table 4-3). This scenario had the lowest mean and median RPDs compared to the mean, median and geometric mean total PCB concentrations. Scenario 3k predicted total PCB concentrations in two of the eight fish species within a factor of two, and six of the eight fish species within a factor of five compared to the measured tissue concentrations. This scenario was used for the sensitivity analysis and uncertainty analysis. The complete results for the modeled scenarios are presented in Appendix B.

The scenarios that included a total PCB water concentration of 2 ng/L consistently outperformed scenarios that used the higher total PCB water concentration of 21 ng/L. Also, the model results using a K_{OW} of 6.3 were generally closer to measured concentrations, as compared to the model results using the higher K_{OW} of 7.3 (Table 4-3). The outcome for PCB water concentration, together with support from past model input values for PCB water concentration (Arnot and Gobas in press; Gobas and Wilcockson 2003) support the use of the lower PCB water concentration. The K_{OW} value needs to be investigated further as the value of this parameter is highly dependent on the mixture of PCBs at the site. The sensitivity and uncertainty of both these parameters should be investigated (see Sections 4.3.2 and 4.3.3).

4.3.2 Sensitivity Analysis Results

For the Gobas model, the most sensitive parameter for scenario 3k was biota lipids. Predicted PCB concentrations increased an average of 12% (with a range of 7-14%) with a 10% increase in biota lipids (Table 4-4). The next most sensitive parameter was PCB sediment concentration, which caused an average increase of 10% in tissue concentrations with a 10% increase in the input data. Increasing sediment OC by 10% caused an average decrease of 9%. The Gobas model is very sensitive to total PCB sediment concentration and sediment OC. This is logical in light of the structure of the Gobas model, which calculates invertebrate concentrations through equilibrium partitioning from chemicals in the sediment.

Parameters other than those described above were also evaluated, but the model was relatively insensitive to changes in these parameters. There was very little change (<1%) in predicted PCB concentration with a 10% increase in PCB water concentration. A 10% increase in biota weights caused an average of 0.5% increase in predicted PCB concentrations in tissue.

4.3.3 Uncertainty Analysis Results

One of the largest uncertainties in the existing environmental data for Portland Harbor is the concentration of PCBs in the water column. PCBs have never been detected in bulk water samples, but the lowest detection limit achieved for the historical data (400 ng/L) was likely much too high to detect PCBs at the Site.. The estimated total PCB concentration from the SPMD data (McCarthy and Gale 1999) appears to be a reasonable estimate based on the model results summarized in Section 4.3.1. However, the additional PCB water data to be collected during Round 2a sampling for the RI/FS may provide more suitable data for the model. Alternate PCB water concentrations were evaluated during the uncertainty analysis for the best-performing model scenario (3k). Changing the total PCB water concentration from 2-400 ng/L resulted in an average 730% increase in predicted tissue concentrations, highlighting the inappropriateness of the previous detection limits for whole water samples (Table 4-4). Changing the total PCBs water concentration value from 2-0.07 ng/L (the estimated total PCB concentration from SPMD deployment during high flow in January to February 1998; McCarthy and Gale [1999]) resulted in an average 4% decrease in predicted tissue concentrations. The relatively small change in model predictions from the relatively large decrease in PCB water concentrations highlights the insensitivity of the model to PCB water concentrations at such low concentrations. Because the SPMDs were deployed during only two seasons (i.e. low flow and high flow), it is impossible to estimate an annual average PCB concentration to which the resident fish species evaluated in this model were exposed. The Round 2a water data should help provide a better estimate of a time-averaged PCB concentration to be used in future modeling efforts.

The total PCB concentration in sediment used as model input is based on a relatively large number (approximately 300) of sediment samples distributed over the entire ISA. There are data gaps in the sediment coverage for specific areas, but the calculated concentration of 508 µg/kg dw is a reasonable estimate of the ISA-wide average. Many more sediment samples (> 400) will be collected during Round 2 sampling and analyzed for total PCBs. These data will help to refine the AWA used as model input, but it is unlikely that this value will change dramatically given the large amount of existing data. The primary assumption made by using a single ISA-wide PCB concentration for sediment is that the resident fish species are exposed to that single concentration, on average, throughout their home range. Of course, fish have preferred habitats, but no attempt was made to model separate PCB concentrations for each species. Such modeling would be difficult to do because the Gobas model uses a single sediment concentration to simultaneously model all the resident fish species. In the future, it may be useful to redesign the model so that fish with high site fidelity are associated with different average PCB sediment concentrations.

One alternate assumption that was evaluated was to computationally exclude the resident fish from the deeper waters in the center of Portland Harbor. At least some of the resident fish species (e.g., carp) prefer shallower water. An alternate AWA was derived for all ISA sediments at depths above -20 ft mean lower low water (MLLW). This AWA was 478 µg/kg dw, which was a 6% decrease from the ISA-wide AWA of 508 µg/kg dw. This relatively small difference in the two AWAs suggests that the assumption that resident fish species are exposed to sediments throughout the ISA should not result in a large difference in predictive power for those fish species that are found throughout the ISA, but only in shallower waters. For the Gobas model, application of the alternate AWA for shallower water resulted in an average change of 6% in predicted tissue concentrations (Table 4-4).

The oligochaete lipid percentage used as model input (8%), although based on recent research (Millward et al. 2001), is higher than values used by some previous researchers (Gobas 1993, Pickard et al. 2001). Decreasing the lipid content from 8% to 1% caused an average decrease of 13% in predicted mean tissue concentrations (Table 4-4).

A default value of 19.8% for phytoplankton for non-lipid organic carbon (NLOC) was selected from the original Gobas (1993) model. Recent research conducted by MacKintosh et al. (2004) has highlighted the importance of this parameter for chemical kinetics in phytoplankton. Review of their research suggested a NLOC percentage of 6.8% might be more appropriate for Portland Harbor. Changing the NLOC from 19.8% to 6.8% caused an average of 0.1% change in predicted tissue concentrations (Table 4-4), suggesting this parameter does not greatly influence the model predictions.

Two different K_{OW}s were tested for this model: 7.3 and 6.3. It is difficult to establish a single K_{OW} for a complex mixture such as PCBs, but the selected values have been used in other applications of PCB food web modeling (e.g., MacKay et al. 1992). One method for deriving an appropriate K_{OW} for total PCBs is to examine the congener composition of the mixture. Nine sediment samples collected during the Round 1 sampling event were analyzed for all 209 PCB congeners. Hawker and Connell (1988) have proposed K_{OW}s for all 209 congeners. Using these K_{OW}s and the PCB congener concentrations in the nine sediment samples, a weighted average K_{OW} of 6.5 was calculated (with a range of 5.9-6.8). This result supports the observation that a K_{OW} of 6.3 outperformed a K_{OW} of 7.3.

The various food webs evaluated in the 24 model scenarios have varying degrees of uncertainty, but it is difficult to quantify this uncertainty. Clearly, the scenarios that included only clam and crayfish as invertebrate prey for all resident fish species oversimplify the food web for many of the species, based on stomach-content analysis. Because many of the resident fish species in the LWR are opportunistic feeders, there is likely to be high temporal and spatial variability in the food web. The need for a more complex representation of the food web will be evaluated following the incorporation of Round 2 sediment and Round 2a water chemistry data into future model runs.

4.3.4 Data Gaps

Because the Gobas model appears relatively insensitive to water concentrations, water chemistry data are not a major data gap for this model. As described in Section 4.3.3, the accuracy of the food webs evaluated is relatively uncertain, but the need for additional characterization of this important parameter can’t be determined until additional field data are incorporated into the model.

4.4 ARNOT AND GOBAS MODEL

4.4.1 Scenario Results

For the Arnot and Gobas model, the scenario that produced the best results was 6l (best literature with no sediment food web, K_{OW} 7.3, and PCB water concentration of 2 ng/L). The results for this scenario placed first for every summary statistic; mean RPDs for the four measured concentration comparisons (i.e., mean, median, geometric mean, and maximum) were significantly lower than for all other scenarios (Table 4-5). Scenario 6l predicted total PCB concentrations in two of the eight fish species within a factor of two, and seven of the eight fish species within a factor of five compared to the mean measured tissue concentrations (Table 4-5). This scenario was used for the sensitivity analysis and uncertainty analysis. The complete results for the modeled scenarios are presented in Appendix C.

Scenarios 3k, 3l, and 6k also outperformed most of the other model scenarios consistently. Scenarios 4k and 4l were almost as successful as scenarios 3k, 3l, 6k, and 6l, which was surprising as those scenarios have very unrealistic food webs with clam and crayfish representing all the invertebrate prey species (Table 4-5).

Scenarios that placed in the top eight places (of 24 model scenarios) all had no sediment in the diet. This may be an indication that the sediment ingestion fractions used as model input are too high for some species. Sediment ingestion fractions for fish were based on the most conservative estimate possible; some estimates were as high as 0.5 (50%). It is not impossible that a fish could eat 50% sediment occasionally; however, as an average preference this is most likely too high.

All scenarios with PCB water concentrations of 2 ng/L resulted in better predictions compared to scenarios with PCB water concentrations of 21 ng/L. Arnot and Gobas (in press) used a PCB water concentration of 1 ng/L. This outcome supports use of the lower PCB water concentration and suggests that the sensitivity and uncertainty of PCB water concentrations be investigated.

There was no consistent pattern for outcomes using the two K_{OW}s.

4.4.2 Sensitivity Analysis Results

For the Arnot and Gobas model, the most sensitive parameter for scenario 6l was PCB water concentration. A 10% increase in PCB water concentration resulted in an 8% increase across all predicted concentrations (Table 4-6). The next most sensitive parameter was biota lipids with an average increase of 6%, although there was more variability between species, as compared to the sensitivity analysis for water (Table 4-6). An increase of 10% in PCB sediment concentration caused an average increase of 2% in tissue concentrations, while a 10% increase in sediment OC caused an average decrease of 2%. A 10% increase in biota weights caused less than 1% increase in tissue concentrations (Table 4-6), so the model output is relatively insensitive to this parameter.

4.4.3 Uncertainty Analysis Results

As discussed in Section 4.3.3, the 2 ng/L used as an estimate for total PCB concentration in water appears to be reasonable based on model output. However, there is some uncertainty regarding how representative this concentration is for other locations and seasons. Changing the total PCBs water concentration value from 2 to 400 ng/L resulted in a 15,455% increase in predicted tissue concentrations (Table 4-6), confirming the hypothesis that the previously achieved detection limit of 400 ng/L was much too high for modeling purposes. Changing the total PCB water concentration value from 2 to 0.07 ng/L resulted in an average 75% decrease in predicted tissue concentrations. The number of predictions that were within a factor of two was 8 out of the 11 biota (9 fish and 2 invertebrates), and the number within a factor of five was 10 out of 11. The mean RPD was -97% (Table 4-6). These results are a significant improvement over the results shown for scenario 6l using 2 ng/L (i.e., 3 out of 11 within a factor of two and 8 out of 11 within a factor of five, and a mean RPD of 717%), suggesting that the lower PCB concentration may be more environmentally realistic.

The sediment PCB concentration used as model input is likely to be a reasonable estimate, as discussed in Section 4.3.3. Changing the total PCB concentration in the sediment from 509 to 479 µg/kg dw (a 6% difference) resulted in an average change of 1% in tissue concentrations (Table 4-6), suggesting that sediment concentrations are less important in the Arnot and Gobas model than they are in the Gobas model.

Two other parameters evaluated during the uncertainty analysis for the Gobas model (Section 4.3.3) showed similar results for the Arnot and Gobas model. Changing the oligochaete lipid content from 8 to 1% caused an average of 10% decrease in predicted tissue concentrations. Changing the NLOC content for phytoplankton from 19.8 to 6.8% caused an average of 1% change in predicted tissue concentrations (increases in some species and decreases in others) (Table 4-6).

4.4.4 Data Gaps

The sensitivity of the model to PCB water concentrations combined with the relative uncertainty of the estimated PCB water concentrations suggests that PCB water concentrations are a data gap. However, this data gap will be filled during Round 2a water sampling. Biota lipid values for those species with measured lipid concentrations are certain, while those derived from the literature are less certain and may require further research. The lipid value for oligochaete (8%) was from one literature source (Millward et al. 2001) and is significantly higher than most other oligochaete lipid values (1%) (Gobas 1993, Arnot and Gobas in press). Other species with uncertain lipid values are amphipod, insect, and bryozoan. Compilation of additional literature data on the percent lipid parameter may be appropriate.

The relative insensitivity of the model to biota weights suggests that the existing values for weights are acceptable, because the potential degree of error for weight is less than 10%.

NLOC for phytoplankton is not a very sensitive parameter; however, the new value is more reliable (Mackintosh et al. 2004), and brings the predictions down for a model that is consistently overpredicting total PCB concentrations in resident fish species.

4.5 TROPHICTRACE MODEL

4.5.1 Scenario Results

Of the 40 scenarios evaluated, the best predictions of PCB concentrations in resident fish were consistently observed for scenarios b and d, which have a K_{OW} value of 6.3

and a total PCB concentration of 2 ng/L in water, respectively (Appendix D). There were no consistent patterns for model outputs based on BSAFs.

Food web scenarios 3b and 6b performed best, and although both results were mostly within the measured concentrations by a factor of two, scenario 3b slightly outperformed scenario 6b, having all results within the measured concentrations by a factor of five (Table 4-7). Both scenarios used the same input parameters, and the only difference between them is their food web structure. The former was based on an equal preference for all available prey items; the latter was derived from the best single technical literature available. Scenario 6b was selected as a best scenario candidate because five of the eight runs using food web 6 had seven of eight RPDs within a factor of two, whereas only two of eight runs using food web 3 had seven of eight RPDs within a factor of two (Appendix D). Sensitivity and uncertainty analyses were performed on the two best scenarios, 3b and 6b.

4.5.2 Sensitivity Analysis Results

The sensitivity analysis for scenario 3b indicates that a 10% increase in lipid content had a strong linear effect (10%) on the model output (Table 4-8a). Ten percent increases to both total PCB concentration in sediment and sediment organic carbon resulted in an almost linear 8% effect, although the latter change resulted in a net decrease in model predictions. Model output was not as sensitive to changes in biota weights (1% effect) and total PCB concentration in water (2% effect).

Similar results were found during the sensitivity analysis for scenario 6b (Table 4-8b). A 10% increase in lipid content had a strong linear effect (10%) on the model output. Ten percent increases to both total PCB concentration in sediment and sediment organic carbon resulted in an almost linear 9% effect, with the latter also resulting in a net decrease in model predictions. Changes to both biota weights and total PCB concentration in water resulted in a 1% change to the model output.

4.5.3 Uncertainty Analysis Results

The uncertainty analyses for scenarios 3b and 6b indicate that changes to the total PCB concentrations in water could severely affect the predictions, depending on the magnitude of the change and the concentration. When the total PCB concentration was changed to the method detection limit (400 ng/L), the mean predicted concentrations were 3,200% higher than the original results for scenario 3b and 2,000% higher than the original results for scenario 6b (Tables 4-8a and 4-8b). In contrast, a 30-fold decrease in PCB water concentrations to 0.07 ng/L resulted in a mean decrease of 16% for scenario 3b and 10% for scenario 6b, suggesting that model output is not very sensitive to these low water concentrations.

A 87.5% decrease in the lipid content of oligochaete worms (8% to 1%) caused a 31% mean decrease in the prediction for scenario 6b (Table 4-8b), and a 12% mean decrease for scenario 3b (Table 4-8a). The large change reflects the model's sensitivity to changes in lipid content, and also indicates that the 8% value used for the model runs may need to be further researched.

A 6% decrease in total PCB concentration in the sediment (509 to 479 µg/kg dw) resulted in an almost linear 5% change for both scenarios (Tables 4-8a and 4-8b), even though neither food web 3 or 6 included direct sediment ingestion by fish. These results highlight the importance of sediment as a pathway for bioaccumulation through invertebrate prey.

4.5.4 Data Gaps

Most of the parameters required to execute TrophicTrace are straightforward and easily obtainable through field-collected data or scientific literature. The sensitivity of the model to lipid content suggests the importance of using accurate values. The lipid concentrations in the resident fish species being modeled are based on data collected during Round 1. Although some uncertainty exists in these values because of the relatively small sample sizes, the data are site-specific and represent reasonable estimates of this parameter. The lipid concentrations in invertebrate species, however, are largely from the scientific literature, with the exception of clam and crayfish, which are also from Round 1. Additional literature research on expected lipid concentrations in invertebrate prey species may be warranted.

The relative uncertainty of the estimated total PCB concentrations in water suggests that total PCB concentrations in water are a data gap. However, this data gap will be filled during Round 2a water sampling. The manner in which the water chemistry data will be incorporated into future food web modeling will be discussed with EPA and its partners.

A comparison of the best results suggests that food webs have an important role in predicting tissue concentration. For a more realistic application of the model to the Portland Harbor system, food webs should account for different cohorts because total PCB concentrations can vary widely, depending on the lipid content of the fish at a particular life stage. Information such as weights and lipid content for individuals within cohorts is also needed if such additional scenarios are to be run.

There is little invertebrate information available for the Portland Harbor system in areas such as species composition and weights, lipid contents, and feeding preferences. Most of the values used for the model were derived from literature using surrogate species or general taxonomic relationships. Similar data gaps also exist for some fish species and feeding preferences. Tissue concentrations for black crappie, for example, were consistently overpredicted across all scenarios. This is likely due to the lack of dietary preferences data for this species. In constructing food webs 4-6, an assumption was made that black crappie had the same dietary preference as smallmouth bass because both fish belong to the same family (Centrarchidae). However, mean smallmouth bass weight is almost twice that of black crappie, so the prey these two species can handle may be quite different. Similar data gaps may exist in the peamouth dietary preferences. Tissue concentrations for peamouth were almost always overpredicted because the food webs assumed that peamouth diet consisted mainly of sediment-based invertebrates. Peamouth are often found higher in the water column, so they may prey more heavily on water-based invertebrates.

The model's sensitivity to total PCB concentration in sediment, coupled with its sensitivity to sediment organic carbon, suggest that the role of sediment in the diet for this model is important. Although the model's sensitivity to total PCB concentration in the sediment may not reflect the significance of this parameter in the Portland Harbor system, it does suggest that the focus of data collection should be on the parameters that most affect the predictions of the model. The sediment chemistry data to be collected during Round 2 will be helpful in refining this important input parameter.

4.6 COMPARISON OF CANDIDATE MODEL PERFORMANCES

Several model selection criteria were evaluated for each model, as described below. Table 4-9 compares these model selection criteria for each model.

4.6.1 Model Suitability to Portland Harbor

All the models have been applied in lakes and some in estuaries and ocean harbors. TrophicTrace is being used for a proposed dredging project in the Mississippi Delta on the Sunflower River (von Stakelberg 2004a). A dynamic version of the Gobas model has been applied to the Hudson River (von Stakelberg 2004b). Mean flow rate (mean discharge) of the Willamette River at Portland is 960 m^3/s, and therefore residence time of the Willamette River within the ISA is much shorter than a lake system (Hope 2003). This may indicate that sediment plays a relatively greater role in contaminant transfer than water, as water is flushed from the system and chemicals in the water may not have time to reach equilibrium with chemicals in sediment or tissue. All the models performed better with lower total PCB water concentrations, which further support the argument that this parameter is a data need, which will be filled during Round 2a sampling.

The models best suited to Portland Harbor's food web are the Gobas and the Arnot and Gobas model as they modeled 16 biota compartments (phytoplankton, zooplankton, 5 invertebrates, and 9 fish) and 17 dietary items (with sediment). TrophicTrace modeled 17 biota compartments (plankton with phyto- and zoo- combined, 7 invertebrates, and 9 fish) but was limited to 10 dietary items per fish, so many biota compartments had to be combined for the food web matrices. None of the models would allow biota dietary intakes to include potential predators. This may be solved by creating different fish cohorts and invertebrate instars. However, with limited biota compartments the benefits of these additions would need to be evaluated.

4.6.2 Fit Between Predicted and Observed Values

TrophicTrace performed better than the other models, with 87% of predictions for fish tissue within a factor of 2 of measured concentrations and 100% of predictions for fish tissue within a factor of 5. The best scenarios, those with predicted fish concentrations closest to measures concentrations, were underpredicting the measured concentrations.

4.6.3 Data Requirements

The models with the simplest input parameters were TrophicTrace and Gobas. Many assumptions are fixed in both models' default parameters and equations. Recently some of the calculations for ingestion rates and other rate constants have been challenged (von Stakelberg 2004a). The Arnot and Gobas model has more complex input parameters as many of the values for biological and physical states or rates can be altered. These values are based on recent research and some will require further research to determine their accuracy. Parameters that need further investigation are lipid values for invertebrates that were derived from literature values, especially oligochaetes, and total PCB concentration in water. More data needs may become apparent as the models are investigated further.

4.6.4 Acceptability of Assumptions and Uncertainty

For the Campfens and MacKay, Gobas, and TrophicTrace models, invertebrate and phytoplankton concentrations are calculated using equilibrium partitioning theory from water, sediment-associated porewater, or sediment. For the Campfens and Mackay model, invertebrate chemical uptake is through water and sediment-associated pore water. For the Gobas model invertebrate concentrations are calculated using lipid content, PCB sediment concentration, density of sediment organic carbon and lipids, and sediment organic carbon content. For phytoplankton a Bioconcentration Factor (BCF) is generated from the lipid content of the organism and the K_{OW} to calculate tissue concentrations. For TrophicTrace, BSAFs are used to calculate invertebrate concentrations for benthic invertebrates. One BSAF is used for all benthic invertebrates. For water-based invertebrates or phytoplankton, a BCF is generated from the lipid content of the organism and the K_{OW} to calculate biota concentrations. In order for TrophicTrace to incorporate sediment in the diet, a BSAF of 1 had to be applied to all benthic invertebrates and a biota compartment needed to be parameterized using sediment organic carbon instead of lipid content values.

For Gobas and TrophicTrace, concentrations in fish tissue were calculated based on the Gobas (1993) equations which used rate constants to estimate uptake and loss from water, sediment, diet, and growth dilution. The Campfens and MacKay model used a similar theory for fish concentrations based on calculated rate constants from loss due to egestion, metabolism, respiration and growth dilution, and uptake from diet, water and/or sediment. The rate constants for Campfens and MacKay, Gobas, and TrophicTrace models are derived from old empirical values and relationships.

The Arnot and Gobas model also uses rate constants derived from recent studies to estimate uptake and loss from water, sediment, diet, and growth dilution (e.g. new allometric relationships for predicting gill ventilation rates). In addition, the Arnot and Gobas model includes a new model for partitioning chemicals into organisms, assuming uptake into both lipids and non-lipid organic matter, and kinetic models for predicting chemical concentrations in algae, phytoplankton, and zooplankton. Furthermore, the model includes a mechanistic model for predicting gastrointestinal magnification of organic chemicals in zooplankton, benthic invertebrates, and fish.

Another assumption common to all models was the combining of biota compartments and dietary items. By lumping species together, the accuracy of lipid content, weight, and feeding preference are all reduced. Also, all models would not allow consumption of potential predators, and this was an unrealistic assumption as the food chain in the Willamette River is not linear by species.

4.6.5 Ease of Model Construction and Implementation

All models used were from pre-existing constructs obtained from the internet or from the author. Thus all the models have a user interface and are accessible to various users. The most difficult model to use was Campfens and MacKay. The old Basic program with its limited compartments, difficult data entry procedures, and fugacity conversions made it difficult to parameterize, run, and interpret results. The other three models were Excel-based and were equally easy to parameterize, run, and interpret results. The Arnot and Gobas model is more transparent than the other models because every equation can be accessed to reveal the model mechanisms.

4.6.6 Summary

Campfens and MacKay will not be considered for further testing due to its poor predictive ability, limited biota compartments, difficult data entry procedures, and fugacity conversions, which made it difficult to parameterize, run, and interpret results. The Gobas and TrophicTrace models are very similar in theory, with slightly different mechanisms for calculating concentrations in invertebrates. Due to the better predictive power of TrophicTrace, the Gobas model will not be considered for further testing.

TrophicTrace had the best predictions, has the simplest input parameters and makes more simple assumptions about the ecosystem. Arnot and Gobas is the most suitable for Portland Harbor in terms of biota as it models the most biota compartments and dietary items, however TrophicTrace has been applied in river systems while Arnot and Gobas has not. Arnot and Gobas makes a similar number of assumptions as TrophicTrace, however its assumptions are for more complex processes and therefore have greater uncertainty. Arnot and Gobas may be more realistic mechanistically as its rate constants and coefficients are based on more up-to-date empirical values. Arnot and Gobas is more transparent in terms of the equations and mechanisms in the model, while TrophicTrace has equations embedded in code.

5.0 RECOMMENDATIONS

5.1 MODEL SELECTION

Based on the model runs described in this memorandum, TrophicTrace is the leading candidate model for the Portland Harbor Superfund Site. The predictions for this model outperformed all other models, and the model is very easy to use. Additional model scenarios may be developed for this model, as described in Section 4.5.4, to make it more realistically represent the Portland Harbor ecosystem. This model, and potentially the Arnot and Gobas model, will be further evaluated after the collection of Round 2 data. Model performance using the expanded data set will be reevaluated at that time.

Further evaluation of the Gobas (1993) and Campfens and MacKay (1997) models is not warranted. Most of the algorithms from Gobas (1993) are already incorporated into TrophicTrace. The Campfens and MacKay (1997) model performed very poorly and is difficult to use in its current format.

5.2 FILLING DATA GAPS

The primary data gap identified in this memorandum is total PCB concentrations in water because only one data point was used. However, this data gap will be filled during upcoming Round 2a sampling. Additional data gaps related to dietary preferences exist, but given the large temporal and spatial variability in such data and the reasonably good performance of the existing model with the current uncertainties in dietary preferences, no additional field data collection is recommended at this time. The technical literature will continue to be reviewed for possible model input data (e.g., lipid concentrations in invertebrate prey species) while Round 2 and 2a sampling is conducted so that improved model predictions can be made once field data are available.

6.0 REFERENCES

Ankley GT, Cook PM, Carlson AR, Call DJ, Swenson JA, Corcoran HF, Hoke RA. 1992. Bioaccumulation of PCBs from sediments by oligochaetes and fishes: comparison of laboratory and field studies. Can J Fish Aquat Sci 49:2080-2085.

Armstrong JL, Armstrong DA , Mathews SB. 1995. Food habits of estuarine staghorn sculpin, *Leptocottus armatus*, with focus on consumption of juvenile Dungeness crab, *Cancer magister*. Fish Bull 93:456-470.

Arnot JA, Gobas FAPC. in press. A food-web bioaccumulation model for organic chemicals in aquatic ecosystems. Environ Chem Toxicol.

Bervoets L, De Bruyn L, Van Ginneken L, Blust R. 2003. Accumulation of ^{137}Cs by larvae of the midge *Chironomus riparius* from sediment: Effect of Potassium. Environ Toxicol Chem. 22:1589–1596.

Buchanan DV, Hooton RM , Moring JR. 1981. Northern squawfish (*Ptychocheilus oregonensis*) predation on juvenile salmonids in sections of the Willamette River basin, Oregon. Can J Fish Aquat Sci 38:360-364.

Burkhard LP. 1998. Comparison of two models for predicting bioaccumulation of hydrophobic organic chemicals in a great lakes food web. Environ Toxicol and Chem. 17(3): 383-393.

Campfens I, MacKay D. 1997. Fugacity-based model of PCB bioaccumulation in complex aquatic food webs. Environ. Sci. Technol. 31(2):577-583.

Campfens J, MacKay D. Modified 1998. Food web Model. [online]. Canadian Environmental Modelling Centre, Trent University. [Accessed 6.14.04]. Available from:<http://www.trentu.ca/cemc/models/modelsDOS.html.>

Cretney WJ, Yunker MB. 2000. Concentration dependency of biota-sediment accumulation factors for chlorinated dibenzo-p-dioxins and dibenzofurans in Dungeness crab (Cancer magister) at marine pulp mill sites in British Columbia, Canada. Environ Toxicol Chem 19:3012-3023.

Drouillard KG, Ciborowski JJH, Lazar R, Haffner GD. 1996. Estimation of the uptake of organochlorines by the mayfly *Hexagenia limbata* (Ephemeroptera: Ephemeridae). Journal of Great Lakes Research 22(1):26-35.

Eisler R. 1986. Polychlorinated biphenyl hazards to fish, wildlife, and invertebrates: a synoptic review. US Fish and Wildlife Service Biological Report 85(1.7). Patuxent Wildlife Research Center, US Fish and Wildlife Service, Laurel, MD.

Evans-White M, Dodds WK, Gray LJ, Fritz KM. 2001. A comparison of trophic ecology of the crayfishes (*Orconectes nais* (Faxon) and *Orconectes neglectus* (Faxon)) and the central stoneroller minnow (*Campostoma anomalum* (Rafinesque)): omnivory in a tallgrass prairie stream. Hydrobiologia 462:131-144.

Foster GD, Brown PD, Crimmins BS. 2002. MD Sea Grant Project R/CBT-36 Final Report : Bioaccumulation dynamics of hydrophobic organic contaminants in the Anacostia River food web [online]. Academy of Natural Sciences, Patrick Center for Environmental Research. Philadelphia, PA. [Cited 6/1/04]. Available from: http://www.acnatsci.org/research/pcer/foodweb.html

Fraser AJ, Burkow IC, Wolkers H, MacKay D. 2002. Modeling biomagnification and metabolism of contaminants in harp seals of the Barents Sea. Environ Toxicol Chem 21:55-61.

Froese R, Pauly D. Editors. 2004. FishBase. World Wide Web electronic publication. <http://www.fishbase.org/home.htm>, version (04/2004). Press, New York, NY.

Gandhi N, Bhavsar SP, Diamond ML, Gregor D, Evenset A, Christensen G. 2004. Factors accounting for high POP concentrations in the aquatic food chain of Lake Ellasjoen, Bear Island, Norway (Abstract from Poster) [Online]. International Association for Great Lakes Research Conference. Waterloo, Ontario, Canada. [Cited 5/25/04]. Available from: <http://www.iaglr.org/conference/2004/abstracts/pub_abstract_view.php?abstract_id=1071269944>

Gewurtz SB. (Current Research). Mechanisms controlling the accumulation of persistent organic pollutants and mercury in the food web of freshwater systems: A case study of Lake Winnipeg, MB, Canada, Lake Labarge YT, Canada and Bear Island, Norway [Online]. Department of Geography, University of Toronto, Canada. [Cited 6/2/04]. Available from: http://www.geog.utoronto.ca/info/facweb/mdiamond/People/Sarah/Sarah%20Gewurtz_files/sarah's%20website%20stuff2.htm

Gobas FAPC. 1993. A model for predicting the bioaccumulation of hydrophobic organic chemicals in aquatic food-webs: Application to Lake Ontario. Ecol Modelling 69:1-17.

Gobas FAPC, Pasternak JP, Lien K, Duncan RK. 1998. Development & field-validation of a multi-media exposure assessment model for waste load allocation in aquatic ecosystems: application to TCDD and TCDF in the Fraser River Watershed. Environ. Sci. Technol. 32:2442-2449.

Gobas FAPC, Wilcockson J. 2003. San Francisco Bay PCB food-web model [online]. San Francisco Estuary Institute. San Francisco Estuary Monitoring Program for Trace Substances. San Francisco Estuary Institute Contribution 90. [Cited 5/3/04]. Available from: http://www.sfei.org/rmp/reports/pcb/pcbfoodweb_final.pdf

Gobas FAPC, Wilcockson J, Russell RW, Haffner GD. 1999. Mechanism of biomagnification in fish under laboratory and field conditions. Environ. Sci. Technol. 33:133-141.

Gobas FAPC, Z'Graggen MN, Zhang X. 1995. Time response of the Lake Ontario ecosystem to virtual elimination of PCBs. Environ Sci Technol 29:2038-2016.

Gray RH , Dauble DD. 2001. Some life history characteristics of cyprinids in the Hanford Reach, mid-Columbia River. Northwest Sci 75(2): 122-133.

Hawker DW, Connell DW. 1988. Octanol-water partition coefficients of PCB congeners. Environ Sci Technol 22:382-387.

Hope B. 2003. Final Report. Willamette River Basin Total Maximum Daily Load Project: Estimates of Mercury Mass Loads and Sources in the Willamette River Basin [online]. Oregon Department of Environmental Quality, Portland, OR. [Cited 6/23/04]. Available from: http://www.oracwa.org/Pages/WRB_Hg_Load_Report_FIN.pdf

Integral, Windward, Kennedy/Jenks, Anchor , Groundwater Solutions. 2004. Portland Harbor remedial investigation/feasibility study programmatic work plan. Revised. Prepared for Lower Willamette Group. Integral Consulting, Inc., Mercer Island, WA; Windward Environmental LLC, Seattle, WA; Kennedy/Jenks Consultants, Federal Way, WA; Anchor Environmental, LLC, Seattle, WA; Groundwater Solutions, Inc., Portland, OR.

Jorgensen SE, Ed. 1979. Handbook of environmental data and ecological parameters. Part A, tables A208-A434. International Society for Ecological Modeling. Pergamon Press, New York, NY.

Kraaij RH, Ciarelli S, Tolls J, Kater BJ, Belfroid A. 2001. Bioavailability of lab-contaminated and native polycyclic aromatic hydrocarbons to the amphipod *Corophium volutator* relates to chemical desorption. Environ Toxicol Chem 20(8): 1716-1724.

Leon H. 1980. Final Report: Terminal 107 environmental studies. Benthic community impact study for terminal 107 (Kellogg Island) and vicinity. Prepared for Port of Seattle Planning and Research Department. Pacific Rim Planners, Inc., Seattle, WA.

Lyytikäinen M, Rantalainen A, Mikkelson P, Hämäläinen H, Paasivirta J, Kukkonen JVK. 2003. Similarities in bioaccumulation patterns of polychlorinated dibenzo-p-dioxins and furans and polychlorinated diphenyl ethers in laboratory-exposed oligochaetes and semipermeable membrane devices and in field-collected chironomids. Environ Toxicol Chem. 22:2405–2415.

Mackintosh CE, Maldonado J, Hongwu J, Hoover N, Chong A, Ikonomou MG, Gobas FAPC. (2004). Distribution of phthalate esters in a marine aquatic food web: comparison to polychlorinated biphenyls. Environ Sci Tech 38:2011-2020.

McCarthy KA, Gale RW. 1999. Investigation of the distribution of organochlorine and polycyclic aromatic hydrocarbon compounds in the lower Columbia River using semipermeable membrane devices. USGS water-resources investigations report 99-4051. US Geological Survey, Portland, OR.

MacKay D, Puig H, McCarty LS. 1992. An equation describing the time course and variability in uptake and toxicity of narcotic chemicals to fish. Environ Toxicol Chem 11:941-951.

Millward RN, Fleeger JW, Reible DD, Keteles KA, Cunningham BP, Zhang L. (2001). Pyrene bioaccumulation, effects of pyrene exposure on particle-size selection, and fecal pyrene content in the oligochaete Limnodrilus hoffmeisteri (Tubificidae, Oligochaeta). Environ Toxicol Chem 20:1359-1366.

Morrison HA, Gobas FAPC, Lazar R, Whittle DM, Haffner GD. 1997. Development and verification of a food-chain bioccumulation model for western Lake Erie. Environ Sci Technol 31:3267-3273.

NYDEC. 1999. Hudson River assessment as a special year for PCB's in Hudson River fish – Tables [online]. New York State Department of Environmental Conservation. [Cited 6/7/04]. Available from: http://www.dec.state.ny.us/website/dfwmr/habitat/nrd/HR99Tables.pdf

ODEQ. 2004. Laboratory analytical storage and retrieval database, list of monitoring stations for USGS Watershed 1709001203. Portland, OR, DEQ Online, Oregon Department of Environmental Quality: data for Willamette River At Sp&S RR Bridge (Portland) and Willamette River At Hawthorne Bridge.

Oliver BG. 1987. Biouptake of chlorinated hydrocarbons from laboratory-spiked and field sediments by oligochaete worms. Environ Sci Technol 21(8):785-790.

ORNL. 1998. Biota sediment accumulation factors for invertebrates: review and recommendations for the Oak Ridge Reservation. BJC/OR-112. Oak Ridge National Laboratory, Oak Ridge, TN.

Pechenik JA. 1991. Biology of the Invertebrates. Dubuque, IA, Wm. C. Brown Publishers.

Pickard SW, Yaksich SM, Irvine KN, McFarland VA. 2001. Bioaccumulation potential of sediment-associated polychlorinated biphenyls (PCBs) in Ashtabula Harbor, Ohio. J Great Lakes Research. 27:44-59

Seth R, Mackay D, Muncke J. 1999. Estimating the organic carbon partition coefficient and its variability for hydrophobic chemicals. Environ Sci Technol 33:2390-2394.

Thomann RV. 1989. Bioaccumulation model of organic chemical distribution in aquatic food chains. Environ Sci Technol 23:699-707.

Thomann RV, Connolly JP, Parkerton TF. 1992. An equilibrium model of organic chemical accumulation in aquatic food webs with sediment interaction. Environ Toxicol Chem 11:615-629.

Turner JL. 1966. Distribution and food habits of Centrarchid fishes in the Sacramento-San Joaquin delta. Fish Bull 136:130-143.

USACE. 2003. TrophicTrace: A tool for assessing risks from trophic transfer of sediment-associated contaminants [online]. United States Army Corps of Engineers and Menzie-Cura & Associates. [Cited 3/23/04]. Available from: http://www.wes.army.mil/el/trophictrace/index.html

von Stackelberg K. 2004a. Personal communication (e-mail to Fiona McNair, Windward Environmental, Seattle, WA regarding past uses of the TrophicTrace model). Consultant, Menzie-Cura & Associates, Inc. Winchester, MA. June 23.

von Stackelberg K. 2004b. Personal communication (e-mail to Fiona McNair, Windward Environmental, Seattle, WA regarding past uses of the TrophicTrace and Gobas models). Consultant, Menzie-Cura & Associates, Inc. Winchester, MA June 6.

Windward. 2004. Portland Harbor Superfund site. Ecological risk assessment: Approach for the preliminary risk evaluation for ecological receptors. Prepared for Lower Willamette Group. Windward Environmental LLC, Seattle, WA.

Zaranko D, Griffiths RW, Kaushik NK. 1997. Biomagnification of polychlorinated biphenyls through a riverine food web. Environ Toxicol Chem 16:1463-1471.

Zimmerman MP. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the Lower Columbia River basin during outmigration of juvenile anadromous salmonids. Trans Am Fish Soc 128:1036-1054.

Appendix A - Summary output for Campfens and MacKay fugacity model

Predicted concentration of total PCBs (μg/kg ww)

Scenario	1i	1j	1k	1l	4i	4j	4k	4l
Black crappie	6.96E+04	2.42E+05	4.97E+05	1.14E+05	4.12E+05	5.39E+05	3.96E+05	4.83E+05
Brown bullhead	4.97E+05	2.91E+05	5.02E+04	2.91E+05	7.48E+03	3.78E+04	7.22E+01	3.65E+03
Carp	1.49E+06	5.09E+05	1.49E+06	5.09E+05	1.20E+06	2.39E+05	1.20E+06	2.39E+05
Largescale sucker	1.93E+04	4.31E+04	1.87E+03	4.13E+03	1.93E+04	4.31E+04	1.87E+03	4.17E+03
Northern pikeminnow	1.20E+05	2.72E+05	9.98E+04	1.58E+05	5.13E+05	6.46E+05	5.00E+05	6.02E+05
Peamouth	na	na	na	na	1.20E+06	2.39E+05	1.20E+06	2.39E+05
Sculpin	1.56E+04	9.84E+04	1.50E+03	9.84E+04	1.02E+06	6.74E+05	1.02E+06	6.74E+05
Smallmouth bass	1.41E+05	3.25E+05	1.22E+05	3.25E+05	5.02E+05	6.11E+05	4.86E+05	5.56E+05

Comparison to mean concentrations of total PCBs (μg/kg ww) as RPD

Scenario	1i	1j	1k	1l	4i	4j	4k	4l
Black crappie	51809%	180614%	370716%	84665%	307154%	402261%	295507%	360467%
Brown bullhead	122893%	71878%	12331%	71878%	1751%	9256%	-82%	804%
Carp	90594%	30975%	90594%	30975%	72923%	14479%	72923%	14479%
Largescale sucker	2261%	5165%	128%	405%	2261%	5165%	128%	409%
Northern pikeminnow	14324%	32533%	11882%	18877%	61507%	77454%	59865%	72112%
Peamouth	na	na	na	na	639531%	127607%	639531%	127607%
Sculpin	2670%	17408%	168%	17408%	180977%	119839%	180977%	119839%
Smallmouth bass	12589%	29079%	10822%	29079%	44966%	54796%	43566%	49814%
mean RPD	42449%	52522%	70949%	36184%	163884%	101357%	161552%	93191%
median RPD	14324%	30975%	11882%	29079%	67215%	66125%	66394%	60963%
Number RPDs less than 100%	0/7	0/7	0/7	0/7	0/8	0/8	1/8	0/8
Number RPDs less than 400%	0/7	0/7	2/7	0/7	0/8	0/8	2/8	0/8

Comparison to median concentrations of total PCBs (μg/kg ww) as RPD

Scenario	1i	1j	1k	1l	4i	4j	4k	4l
Black crappie	69458%	242057%	496794%	113486%	411621%	539064%	396014%	483060%
Brown bullhead	388098%	227080%	39134%	227080%	5741%	29430%	-44%	2753%
Carp	174673%	59784%	174673%	59784%	140619%	27995%	140619%	27995%
Largescale sucker	3480%	7886%	246%	665%	3480%	7886%	246%	672%
Northern pikeminnow	17313%	39296%	14365%	22810%	74275%	93527%	72293%	87078%
Peamouth	na	na	na	na	742825%	148230%	742825%	148230%
Sculpin	5753%	36890%	466%	36890%	382477%	253305%	382477%	253305%
Smallmouth bass	18007%	41536%	15485%	41536%	64205%	78233%	62208%	71124%
mean RPD	96683%	93504%	105880%	71750%	228155%	147209%	224580%	134277%
median RPD	18007%	41536%	15485%	41536%	107447%	85880%	106456%	79101%
Number RPDs less than 100%	0/7	0/7	0/7	0/7	0/8	0/8	1/8	0/8
Number RPDs less than 400%	0/7	0/7	1/7	0/7	0/8	0/8	2/8	0/8

Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD

Scenario	1i	1j	1k	1l	4i	4j	4k	4l
Black crappie	57865%	201698%	413978%	94555%	343001%	449203%	329995%	402534%
Brown bullhead	257358%	150569%	25920%	150569%	3774%	19485%	-63%	1792%
Carp	177387%	60714%	177387%	60714%	142804%	28432%	142804%	28432%
Largescale sucker	3555%	8052%	253%	681%	3555%	8052%	253%	688%
Northern pikeminnow	16564%	37603%	13743%	21825%	71077%	89501%	69180%	83329%
Peamouth	na	na	na	na	668118%	133314%	668118%	133314%
Sculpin	4812%	30939%	375%	30939%	320927%	212536%	320927%	212536%
Smallmouth bass	19681%	45384%	16926%	45384%	70149%	85473%	67967%	77707%
mean RPD	76746%	76423%	92655%	57810%	202926%	128250%	199898%	117542%
median RPD	19681%	45384%	16926%	45384%	106941%	87487%	105992%	80518%
Number RPDs less than 100%	0/7	0/7	0/7	0/7	0/8	0/8	1/8	0/8
Number RPDs less than 400%	0/7	0/7	2/7	0/7	0/8	0/8	2/8	0/8

Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD

Scenario	1i	1j	1k	1l	4i	4j	4k	4l
Black crappie	27723%	96763%	198657%	45334%	164588%	215565%	158345%	193164%
Brown bullhead	29129%	17005%	2854%	17005%	340%	2123%	-96%	115%
Carp	22755%	7731%	22755%	7731%	18302%	3574%	18302%	3574%
Largescale sucker	857%	2035%	-8%	105%	857%	2035%	-8%	106%
N. pikeminnow	6575%	15002%	5445%	8682%	28410%	35790%	27651%	33318%
Peamouth	na	na	na	na	412352%	82249%	412352%	82249%
Sculpin	363%	2828%	-55%	2828%	30187%	19961%	30187%	19961%
Smallmouth bass	3039%	7117%	2601%	7117%	11046%	13478%	10700%	12245%
mean RPD	12920%	21212%	33179%	12686%	83260%	46847%	82179%	43092%
median RPD	6575%	7731%	2854%	7731%	23356%	16719%	22976%	16103%
Number RPDs less than 100%	0/7	0/7	2/7	0/7	0/8	0/8	2/8	0/8
Number RPDs less than 400%	1/7	0/7	2/7	1/7	1/8	0/8	2/8	2/8

na – not applicable
RPD – relative percent difference

Appendix B - Summary output for Gobas fugacity model

Predicted concentration of total PCBs (µg/kg ww)												
Scenario	**5h**	**5j**	**5g**	**5i**	**6j**	**6l**	**6i**	**6k**	**2h**	**2j**	**2g**	**2i**
Mollusk	294	294	294	294	294	294	294	294	294	294	294	294
Oligochaete	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612
Insect	392	392	392	392	392	392	392	392	392	392	392	392
Amphipod	261	261	261	261	261	261	261	261	261	261	261	261
Crayfish	261	261	261	261	261	261	261	261	261	261	261	261
Carp	1,397	1,272	1,408	1,238	935	741	914	719	1,232	1,177	1,294	1,150
Largescale sucker	1,557	1,383	1,539	1,320	1,254	977	1,184	928	2,757	2,098	2,364	1,971
Chinook	1,193	1,013	1,009	687	1,193	1,013	1,009	687	1,193	1,013	1,009	687
Sculpin	2,453	2,241	2,070	1,683	2,712	2,480	2,253	1,847	2,083	1,346	1,502	904
Peamouth	927	566	906	529	876	503	851	470	2,535	1,620	1,997	1,222
Black crappie	6,505	5,715	5,235	4,027	6,966	6,021	5,445	4,128	3,226	2,014	2,270	1,376
Brown bullhead	1,526	1,431	1,304	1,110	1,241	1,139	1,078	879	2,431	1,838	1,690	1,144
Smallmouth bass	6,245	5,579	5,104	4,002	6,712	5,900	5,324	4,117	4,937	3,326	3,501	2,311
Northern pikeminnow	3,613	3,285	3,114	2,568	3,868	3,499	3,268	2,686	6,374	4,581	4,687	3,222
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD												
Mollusk	242%	242%	242%	242%	242%	242%	242%	242%	242%	242%	242%	242%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	743%	743%	743%	743%	743%	743%	743%	743%	743%	743%	743%	743%
Carp	-15%	-22%	-14%	-24%	-43%	-55%	-44%	-56%	-25%	-28%	-21%	-30%
Largescale sucker	90%	69%	88%	61%	53%	19%	45%	13%	237%	156%	189%	141%
Chinook	2031%	1708%	1702%	1127%	2031%	1708%	1702%	1127%	2031%	1708%	1702%	1127%
Sculpin	336%	299%	268%	199%	383%	341%	301%	229%	271%	140%	167%	61%
Peamouth	395%	203%	385%	183%	369%	169%	355%	151%	1256%	766%	968%	554%
Black crappie	4754%	4165%	3807%	2905%	5098%	4393%	3964%	2981%	2307%	1403%	1594%	927%
Brown bullhead	278%	254%	223%	175%	207%	182%	167%	118%	502%	355%	318%	183%
Smallmouth bass	461%	401%	359%	260%	503%	430%	378%	270%	344%	199%	215%	108%
Northern pikeminnow	334%	294%	274%	208%	364%	320%	292%	222%	665%	450%	463%	287%
Mean RPD	877%	760%	734%	553%	905%	772%	740%	549%	779%	558%	598%	395%
Median RPD	336%	294%	274%	208%	369%	320%	301%	229%	502%	355%	318%	242%
Number RPDs less than 100%	2/9	2/11	2/11	2/11	2/11	2/11	2/11	2/11	1/11	1/11	1/11	2/11
Number RPDs less than 400%	7/11	7/11	8/11	8/11	7/11	7/11	8/11	8/11	5/11	6/11	6/11	7/11

na – not applicable
RPD – relative percent difference

Comparison to median concentrations of total PCBs (µg/kg ww) as RPD												
Scenario	**5h**	**5j**	**5g**	**5i**	**6j**	**6l**	**6i**	**6k**	**2h**	**2j**	**2g**	**2i**
Mollusk	282%	282%	282%	282%	282%	282%	282%	282%	282%	282%	282%	282%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%
Carp	64%	50%	66%	46%	10%	-13%	8%	-15%	45%	38%	52%	35%
Largescale sucker	188%	156%	185%	145%	132%	81%	119%	72%	411%	289%	338%	265%
Chinook	2031%	1708%	1702%	1127%	2031%	1708%	1702%	1127%	2031%	1708%	1702%	1127%
Sculpin	822%	742%	678%	533%	920%	832%	747%	594%	683%	406%	465%	240%
Peamouth	475%	252%	463%	229%	444%	212%	429%	192%	1475%	906%	1141%	659%
Black crappie	6405%	5615%	5135%	3927%	6866%	5921%	5345%	4028%	3126%	1914%	2170%	1276%
Brown bullhead	1092%	1018%	918%	767%	869%	790%	742%	587%	1799%	1336%	1220%	794%
Smallmouth bass	701%	615%	554%	413%	760%	656%	583%	428%	533%	326%	349%	196%
Northern pikeminnow	424%	376%	351%	272%	461%	407%	374%	289%	824%	564%	579%	367%
Mean RPD	1497%	1345%	1301%	1065%	1523%	1351%	1301%	1051%	1381%	1068%	1116%	838%
Median RPD	701%	615%	554%	413%	760%	656%	583%	428%	824%	564%	579%	367%
Number RPDs less than 100%	1/11	1/11	1/11	1/11	1/11	2/11	1/11	2/11	1/11	1/11	1/11	1/11
Number RPDs less than 400%	3/11	5/11	4/11	5/11	3/11	4/11	4/11	5/11	2/11	4/11	4/11	6/11
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD												
Mollusk	254%	254%	254%	254%	254%	254%	254%	254%	254%	254%	254%	254%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%
Carp	67%	52%	68%	48%	12%	-11%	9%	-14%	47%	41%	55%	37%
Largescale sucker	194%	161%	191%	150%	137%	85%	124%	75%	421%	297%	347%	273%
Chinook	2240%	1886%	1879%	1247%	2240%	1886%	1879%	1247%	2240%	1886%	1879%	1247%
Sculpin	674%	607%	553%	431%	756%	682%	611%	483%	557%	325%	374%	185%
Peamouth	418%	216%	406%	196%	390%	181%	376%	163%	1316%	805%	1016%	583%
Black crappie	5320%	4663%	4262%	3255%	5705%	4918%	4438%	3340%	2588%	1579%	1792%	1046%
Brown bullhead	691%	641%	575%	475%	543%	490%	459%	355%	1160%	852%	776%	493%
Smallmouth bass	775%	681%	615%	460%	840%	726%	646%	477%	591%	366%	390%	224%
Northern pikeminnow	401%	356%	332%	256%	436%	385%	353%	272%	784%	535%	550%	347%
Mean RPD	1192%	1054%	1019%	804%	1217%	1061%	1020%	794%	1094%	820%	864%	615%
Median RPD	674%	607%	553%	431%	543%	490%	459%	355%	784%	535%	550%	347%
Number RPDs less than 100%	1/11	1/11	1/11	1/11	1/11	2/11	1/11	2/11	1/11	1/11	1/11	1/11
Number RPDs less than 400%	3/11	5/11	4/11	5/11	4/11	5/11	5/11	6/11	2/11	5/11	5/11	6/11

RPD – relative percent difference
na - not applicable

Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD												
Scenario	**5h**	**5j**	**5g**	**5i**	**6j**	**6l**	**6i**	**6k**	**2h**	**2j**	**2g**	**2i**
Mollusk	145%	145%	145%	145%	145%	145%	145%	145%	145%	145%	145%	145%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%
Carp	-79%	409%	463%	395%	274%	197%	266%	188%	393%	371%	418%	360%
Largescale sucker	-23%	-19%	-9%	-22%	-26%	-43%	-30%	-45%	62%	23%	39%	16%
Chinook	1093%	-84%	-84%	-89%	-82%	-84%	-84%	-89%	-82%	-84%	-84%	-89%
Sculpin	-27%	-66%	-68%	-74%	-58%	-62%	-65%	-72%	-68%	-79%	-77%	-86%
Peamouth	219%	-72%	-55%	-74%	-57%	-75%	-58%	-77%	26%	-20%	-1%	-39%
Black crappie	2502%	218%	191%	124%	287%	235%	203%	129%	79%	12%	26%	-24%
Brown bullhead	-10%	393%	349%	283%	328%	293%	272%	203%	738%	534%	483%	295%
Smallmouth bass	39%	66%	52%	19%	100%	76%	58%	23%	47%	-1%	4%	-31%
Northern pikeminnow	101%	-27%	-31%	-43%	-14%	-22%	-27%	-40%	42%	2%	4%	-28%
Mean RPD	359%	87%	86%	60%	81%	59%	61%	32%	125%	81%	86%	46%
Median RPD	39%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	47%	2%	4%	-24%
Number RPDs less than 100%	6/11	7/11	7/11	7/11	7/11	7/11	7/11	7/11	8/11	8/11	8/11	8/11
Number RPDs less than 400%	9/11	10/11	10/11	11/11	11/11	11/11	11/11	11/11	10/11	10/11	9/11	11/11

RPD – relative percent difference
na - not applicable

Predicted concentration of total PCBs (µg/kg ww)												
Scenario	**3j**	**3l**	**3i**	**3k**	**4j**	**4l**	**4i**	**4k**	**1j**	**1l**	**1i**	**1k**
Mollusk	294	294	294	294	392	392	392	392	392	392	392	392
Oligochaete	2,612	2,612	2,612	2,612								
Insect	392	392	392	392								
Amphipod	261	261	261	261								
Crayfish	261	261	261	261	261	261	261	261	261	261	261	261
Carp	1,023	968	1,092	947	984	929	1,054	910	1,215	1,160	1,278	1,134
Largescale sucker	2,915	2,162	2,453	2,025	1,222	1,152	1,288	1,107	1,222	1,152	1,288	1,107
Chinook	1,193	1,013	1,009	687	1,228	1,047	1,032	710	1,228	1,047	1,032	710
Sculpin	2,119	1,290	1,478	838	2,250	1,913	1,808	1,234	2,236	1,872	1,774	1,163
Peamouth	2,634	1,578	1,994	1,141	1,253	1,137	1,365	1,074	3,674	3,089	3,085	2,049
Black crappie	3,525	2,025	2,348	1,295	6,223	5,324	4,941	3,424	4,372	3,653	3,366	2,190
Brown bullhead	2,550	1,823	1,705	1,083	1,345	1,202	1,127	865	3,538	2,994	2,438	1,649
Smallmouth bass	5,549	3,529	3,761	2,345	5,834	4,982	4,646	3,203	6,792	5,668	4,861	3,145
Northern pikeminnow	7,147	4,829	5,016	3,256	4,303	3,686	3,465	2,415	10,203	8,570	7,362	4,869
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD												
Mollusk	242%	242%	242%	242%	356%	356%	356%	356%	356%	356%	356%	356%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	743%	743%	743%	743%	743%	743%	743%	743%	743%	743%	743%	743%
Carp	-38%	-41%	-33%	-42%	-40%	-43%	-36%	-44%	-26%	-29%	-22%	-31%
Largescale sucker	256%	164%	199%	147%	49%	41%	57%	35%	49%	41%	57%	35%
Chinook	2031%	1708%	1702%	1127%	2093%	1770%	1743%	1167%	2093%	1770%	1743%	1167%
Sculpin	277%	130%	163%	49%	300%	240%	222%	120%	298%	233%	216%	107%
Peamouth	1308%	744%	966%	510%	570%	508%	630%	474%	1865%	1552%	1550%	996%
Black crappie	2530%	1411%	1652%	866%	4544%	3873%	3587%	2455%	3163%	2626%	2412%	1534%
Brown bullhead	531%	351%	322%	168%	233%	198%	179%	114%	776%	641%	503%	308%
Smallmouth bass	399%	217%	238%	111%	424%	348%	317%	188%	510%	409%	337%	183%
Northern pikeminnow	758%	480%	502%	291%	417%	342%	316%	190%	1125%	929%	784%	485%
Mean RPD	822%	559%	609%	383%	881%	761%	738%	527%	995%	843%	789%	535%
Median RPD	531%	351%	322%	242%	417%	348%	317%	190%	743%	641%	503%	356%
Number RPDs less than 100%	1/11	1/11	1/11	2/11	2/11	2/11	2/11	2/11	2/11	2/11	2/11	2/11
Number RPDs less than 400%	5/11	6/11	6/11	7/11	5/11	7/11	7/11	7/11	4/11	4/11	5/11	6/11

RPD – relative percent difference
na - not applicable

Comparison to median concentrations of total PCBs (µg/kg ww) as RPD												
Scenario	**3j**	**3l**	**3i**	**3k**	**4j**	**4l**	**4i**	**4k**	**1j**	**1l**	**1i**	**1k**
Mollusk	282%	282%	282%	282%	409%	409%	409%	409%	409%	409%	409%	409%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%	3981%
Carp	20%	14%	28%	11%	16%	9%	24%	7%	43%	37%	50%	33%
Largescale sucker	440%	300%	354%	275%	126%	113%	139%	105%	126%	113%	139%	105%
Chinook	2031%	1708%	1702%	1127%	2093%	1770%	1743%	1167%	2093%	1770%	1743%	1167%
Sculpin	697%	385%	456%	215%	746%	619%	580%	364%	741%	604%	567%	337%
Peamouth	1536%	880%	1138%	609%	678%	606%	748%	567%	2182%	1819%	1816%	1172%
Black crappie	3425%	1925%	2248%	1195%	6123%	5224%	4841%	3324%	4272%	3553%	3266%	2090%
Brown bullhead	1892%	1325%	1232%	746%	950%	839%	781%	576%	2664%	2239%	1805%	1188%
Smallmouth bass	611%	352%	382%	201%	648%	539%	496%	311%	771%	627%	523%	303%
Northern pikeminnow	936%	600%	627%	372%	524%	434%	402%	250%	1379%	1142%	967%	606%
Mean RPD	1441%	1068%	1130%	819%	1481%	1322%	1286%	1006%	1696%	1481%	1388%	1036%
Median RPD	936%	600%	627%	372%	678%	606%	580%	409%	1379%	1142%	967%	606%
Number RPDs less than 100%	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11
Number RPDs less than 400%	2/11	5/11	4/11	6/11	2/11	2/11	2/11	5/11	2/11	2/11	2/11	4/11
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD												
Mollusk	254%	254%	254%	254%	372%	372%	372%	372%	372%	372%	372%	372%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%	2076%
Carp	22%	16%	30%	13%	18%	11%	26%	9%	45%	39%	53%	35%
Largescale sucker	451%	309%	364%	283%	131%	118%	144%	109%	131%	118%	144%	109%
Chinook	2240%	1886%	1879%	1247%	2308%	1953%	1924%	1291%	2308%	1953%	1924%	1291%
Sculpin	568%	307%	366%	164%	610%	504%	470%	289%	605%	490%	460%	267%
Peamouth	1371%	781%	1014%	538%	600%	535%	662%	500%	1953%	1626%	1624%	1044%
Black crappie	2837%	1588%	1857%	979%	5086%	4337%	4018%	2753%	3543%	2944%	2705%	1725%
Brown bullhead	1221%	845%	783%	461%	597%	523%	484%	348%	1733%	1451%	1163%	754%
Smallmouth bass	677%	394%	427%	228%	717%	598%	551%	349%	851%	694%	581%	340%
Northern pikeminnow	891%	570%	596%	352%	497%	411%	381%	235%	1315%	1089%	921%	575%
Mean RPD	1146%	820%	877%	600%	1183%	1040%	1010%	757%	1358%	1168%	1093%	781%
Median RPD	891%	570%	596%	352%	600%	523%	484%	349%	1315%	1089%	921%	575%
Number RPDs less than 100%	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11	1/11
Number RPDs less than 400%	2/11	5/11	4/11	6/11	3/11	3/11	4/11	7/11	3/11	3/11	3/11	5/11

RPD – relative percent difference
na - not applicable

Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD												
Scenario	**3j**	**3l**	**3i**	**3k**	**4j**	**4l**	**4i**	**4k**	**1j**	**1l**	**1i**	**1k**
Mollusk	145%	145%	145%	145%	226%	226%	226%	226%	226%	226%	226%	226%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%	-7%
Carp	309%	287%	337%	279%	294%	272%	322%	264%	386%	364%	411%	354%
Largescale sucker	71%	27%	44%	19%	-28%	-32%	-24%	-35%	-28%	-32%	-24%	-35%
Chinook	-82%	-84%	-84%	-89%	-81%	-84%	-84%	-89%	-81%	-84%	-84%	-89%
Sculpin	-67%	-80%	-77%	-87%	-65%	-71%	-72%	-81%	-66%	-71%	-73%	-82%
Peamouth	30%	-22%	-1%	-44%	-38%	-44%	-32%	-47%	82%	53%	53%	1%
Black crappie	96%	13%	30%	-28%	246%	196%	175%	90%	143%	103%	87%	22%
Brown bullhead	779%	529%	488%	274%	364%	315%	289%	198%	1120%	932%	741%	469%
Smallmouth bass	65%	5%	12%	-30%	74%	48%	38%	-5%	102%	69%	45%	-6%
Northern pikeminnow	59%	7%	11%	-28%	-4%	-18%	-23%	-46%	127%	90%	64%	8%
Mean RPD	127%	75%	82%	37%	89%	73%	73%	43%	182%	149%	131%	78%
Median RPD	65%	7%	12%	-28%	-4%	-7%	-7%	-7%	102%	69%	53%	1%
Number RPDs less than 100%	8/11	8/11	8/11	8/11	7/11	7/11	7/11	8/11	5/11	7/11	8/11	8/11
Number RPDs less than 400%	10/11	10/11	10/11	11/11	11/11	11/11	11/11	11/11	10/11	10/11	9/11	10/11

RPD – relative percent difference
na - not applicable

Appendix C - Summary output for Arnot and Gobas model

Predicted concentration of total PCBs (µg/kg ww)												
Scenario	**5h**	**5j**	**5g**	**5i**	**6j**	**6l**	**6i**	**6k**	**2h**	**2j**	**2g**	**2i**
Mollusk	937	159	705	143	942	119	734	123	937	159	705	143
Oligochaete	4,785	2,253	3,922	1,765	5,012	599	5,284	773	4,785	2,253	3,922	1,765
Insect	1,360	336	826	217	1,371	176	917	154	1,360	336	826	217
Amphipod	1,238	364	771	219	1,054	131	755	119	1,238	364	771	219
Crayfish	3,104	1,026	2,175	723	3,094	362	2,506	360	3,104	1,026	2,175	723
Carp	13,751	5,852	17,758	7,659	18,309	2,118	22,968	3,110	13,374	4,668	14,289	5,300
Largescale sucker	8,243	3,887	11,794	5,211	8,874	1,020	12,894	1,638	14,611	4,894	15,576	5,203
Chinook	7,932	2,151	5,130	1,402	7,941	953	5,695	843	7,932	2,151	5,130	1,402
Sculpin	9,814	3,802	7,748	3,031	10,747	1,288	9,711	1,414	13,219	3,587	9,092	2,567
Peamouth	6,790	1,069	11,334	1,693	6,836	755	11,524	1,360	26,471	7,091	25,429	6,941
Black crappie	41,105	15,381	45,310	16,631	45,369	5,352	53,841	7,389	29,321	8,148	23,408	6,787
Brown bullhead	6,909	2,994	5,406	2,568	7,560	921	5,963	896	17,638	4,929	12,528	3,558
Smallmouth bass	39,570	15,492	42,016	16,739	43,900	5,203	50,802	7,093	49,819	14,269	46,036	13,708
Northern pikeminnow	26,135	9,435	25,912	9,348	28,572	3,398	31,674	4,507	78,581	22,818	79,859	24,088
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD												
Mollusk	989%	85%	720%	67%	995%	38%	754%	43%	989%	85%	720%	67%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	9913%	3211%	6916%	2232%	9880%	1068%	7984%	1060%	9913%	3211%	6916%	2232%
Carp	740%	257%	984%	368%	1018%	29%	1302%	90%	717%	185%	772%	224%
Largescale sucker	906%	375%	1340%	536%	984%	25%	1474%	100%	1684%	498%	1802%	535%
Chinook	14065%	3741%	9061%	2403%	14080%	1601%	10069%	1406%	14065%	3741%	9061%	2403%
Sculpin	1646%	576%	1279%	439%	1812%	129%	1628%	152%	2252%	538%	1518%	357%
Peamouth	3531%	471%	5961%	805%	3555%	304%	6062%	627%	14056%	3692%	13499%	3612%
Black crappie	30575%	11378%	33713%	12311%	33758%	3894%	40080%	5414%	21781%	5981%	17368%	4965%
Brown bullhead	1610%	641%	1238%	536%	1771%	128%	1376%	122%	4266%	1120%	3001%	781%
Smallmouth bass	3455%	1292%	3675%	1404%	3844%	368%	4464%	537%	4376%	1182%	4036%	1132%
Northern pikeminnow	3037%	1033%	3011%	1022%	3330%	308%	3702%	441%	9334%	2639%	9487%	2792%
Mean RPD	6406%	2096%	6173%	2011%	6821%	717%	7172%	908%	7585%	2079%	6198%	1736%
Median RPD	3037%	641%	3011%	805%	3330%	304%	3702%	441%	4376%	1182%	4036%	1132%
Number RPDs less than 100%	0/11	1/11	0/11	1/11	0/11	3/11	0/11	2/11	0/11	1/11	0/11	1/11
Number RPDs less than 400%	0/11	3/11	0/11	2/11	0/11	8/11	0/11	5/11	0/11	2/11	0/11	3/11

na – not applicable
RPD – relative percent difference

Comparison to median concentrations of total PCBs (µg/kg ww) as RPD												
Scenario	**5h**	**5j**	**5g**	**5i**	**6j**	**6l**	**6i**	**6k**	**2h**	**2j**	**2g**	**2i**
Mollusk	1116%	107%	815%	86%	1123%	54%	853%	60%	1116%	107%	815%	86%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	48401%	15938%	33882%	11196%	48240%	5558%	39056%	5518%	48401%	15938%	33882%	11196%
Carp	1518%	588%	1989%	801%	2054%	149%	2602%	266%	1473%	449%	1581%	523%
Largescale sucker	1426%	620%	2084%	865%	1543%	89%	2288%	203%	2606%	806%	2784%	863%
Chinook	14065%	3741%	9061%	2403%	14080%	1601%	10069%	1406%	14065%	3741%	9061%	2403%
Sculpin	3589%	1329%	2813%	1039%	3940%	384%	3551%	432%	4870%	1248%	3318%	865%
Peamouth	4117%	564%	6940%	952%	4146%	369%	7058%	745%	16342%	4304%	15695%	4211%
Black crappie	41005%	15281%	45210%	16531%	45269%	5252%	53741%	7289%	29221%	8048%	23308%	6687%
Brown bullhead	5297%	2239%	4124%	1907%	5806%	620%	4559%	600%	13680%	3751%	9688%	2680%
Smallmouth bass	4973%	1886%	5287%	2046%	5528%	567%	6413%	809%	6287%	1729%	5802%	1657%
Northern pikeminnow	3688%	1267%	3655%	1255%	4041%	392%	4490%	553%	11289%	3207%	11474%	3391%
Mean RPD	11745%	3960%	10533%	3553%	12343%	1367%	12244%	1625%	13577%	3939%	10673%	3142%
Median RPD	4117%	1329%	4124%	1255%	4146%	392%	4559%	600%	11289%	3207%	9061%	2403%
Number RPDs less than 100%	0/11	0/11	0/11	1/11	0/11	2/11	0/11	1/11	0/11	0/11	0/11	1/11
Number RPDs less than 400%	0/11	1/11	0/11	1/11	0/11	6/11	0/11	3/11	0/11	1/11	0/11	1/11
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD												
Mollusk	1029%	92%	749%	73%	1035%	43%	784%	49%	1029%	92%	749%	73%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	25767%	8454%	18024%	5924%	25682%	2917%	20783%	2896%	25767%	8454%	18024%	5924%
Carp	1543%	599%	2022%	815%	2088%	153%	2644%	272%	1498%	458%	1607%	533%
Largescale sucker	1458%	635%	2129%	885%	1578%	93%	2337%	210%	2662%	825%	2844%	884%
Chinook	15454%	4118%	9959%	2648%	15470%	1768%	11066%	1553%	15454%	4118%	9959%	2648%
Sculpin	2996%	1099%	2344%	856%	3290%	306%	2963%	346%	4070%	1031%	2768%	710%
Peamouth	3693%	497%	6232%	846%	3719%	322%	6338%	660%	14688%	3861%	14106%	3777%
Black crappie	34154%	12717%	37658%	13759%	37708%	4360%	44768%	6058%	24334%	6690%	19406%	5556%
Brown bullhead	3480%	1451%	2701%	1231%	3817%	377%	2990%	364%	9039%	2454%	6391%	1743%
Smallmouth bass	5442%	2070%	5785%	2244%	6048%	629%	7015%	893%	6877%	1898%	6348%	1820%
Northern pikeminnow	3525%	1209%	3494%	1197%	3863%	371%	4293%	525%	10799%	3065%	10976%	3241%
Mean RPD	8958%	2995%	8282%	2771%	9482%	1031%	9635%	1257%	10565%	2995%	8471%	2446%
Median RPD	3525%	1209%	3494%	1197%	3817%	371%	4293%	525%	9039%	2454%	6391%	1820%
Number RPDs less than 100%	0/11	1/11	0/11	1/11	0/11	2/11	0/11	1/11	0/11	1/11	0/11	1/11
Number RPDs less than 400%	0/11	1/11	0/11	1/11	0/11	7/11	0/11	5/11	0/11	1/11	0/11	1/11

na – not applicable
RPD – relative percent difference

Comparison to maximum concentrations of total PCBs (µg/kg ww) as relative percent difference (RPD)												
Scenario	**5h**	**5j**	**5g**	**5i**	**6j**	**6l**	**6i**	**6k**	**2h**	**2j**	**2g**	**2i**
Mollusk	681%	33%	487%	19%	685%	-1%	512%	3%	681%	33%	487%	19%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	1009%	267%	677%	158%	1005%	29%	795%	28%	1009%	267%	677%	158%
Carp	112%	2241%	7003%	2963%	7224%	747%	9087%	1144%	5250%	1767%	5616%	2020%
Largescale sucker	308%	129%	594%	207%	422%	-40%	658%	-4%	759%	188%	816%	206%
Chinook	7832%	-67%	-21%	-78%	22%	-85%	-12%	-87%	22%	-67%	-21%	-78%
Sculpin	192%	-42%	19%	-53%	65%	-80%	49%	-78%	103%	-45%	40%	-61%
Peamouth	2241%	-47%	461%	-16%	238%	-63%	470%	-33%	1210%	251%	1159%	244%
Black crappie	16342%	754%	2417%	824%	2421%	197%	2891%	311%	1529%	353%	1200%	277%
Brown bullhead	306%	932%	1764%	786%	2507%	218%	1956%	209%	5982%	1600%	4220%	1127%
Smallmouth bass	779%	361%	1150%	398%	1207%	55%	1412%	111%	1383%	325%	1270%	308%
Northern pikeminnow	1352%	110%	476%	108%	535%	-24%	604%	0%	1646%	407%	1675%	435%
Mean RPD	2832%	425%	1366%	483%	1485%	87%	1675%	146%	1779%	462%	1558%	423%
Median RPD	779%	129%	594%	158%	685%	-1%	658%	3%	1210%	267%	1159%	244%
Number RPDs less than 100%	0/11	4/11	2/11	4/11	2/11	8/11	2/11	7/11	1/11	3/11	2/11	3/11
Number RPDs less than 400%	4/11	8/11	2/11	8/11	3/11	10/11	2/11	10/11	2/11	8/11	2/11	8/11

na – not applicable
RPD – relative percent difference

Predicted concentration of total PCBs (µg/kg ww)												
Scenario	**3j**	**3l**	**3i**	**3k**	**4j**	**4l**	**4i**	**4k**	**1j**	**1l**	**1i**	**1k**
Mollusk	942	119	734	123	1310	166	892	150	1310	166	892	150
Oligochaete	5012	599	5284	773	na	na	na	na	na	na	na	na
Insect	1371	176	917	154	na	na	na	na	na	na	na	na
Amphipod	1054	131	755	119	na	na	na	na	na	na	na	na
Crayfish	3094	362	2506	360	2826	333	2452	329	2826	333	2452	329
Carp	14280	1710	15940	2373	23648	2780	29007	3869	17127	2060	19532	2773
Largescale sucker	15732	1810	18797	2587	16246	1952	17961	2545	16246	1952	17961	2545
Chinook	7941	953	5695	843	9012	1076	6744	942	9012	1076	6744	942
Sculpin	13896	1627	10299	1471	17367	2096	13041	1885	21632	2581	16975	2365
Peamouth	28714	3349	29284	4113	16160	1937	18072	2547	61427	7329	63637	8869
Black crappie	32483	3784	27688	3921	74343	8937	73350	10438	61862	7367	55934	7752
Brown bullhead	18997	2240	14541	2073	18209	2153	16709	2270	33347	3980	25892	3611
Smallmouth bass	56363	6572	56036	7896	69633	8374	67951	9685	110670	13184	107869	14964
Northern pikeminnow	88884	10405	96657	13709	59077	7084	57740	8155	194764	23219	210316	29240
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD												
Mollusk	995%	38%	754%	43%	1424%	93%	937%	75%	1424%	93%	937%	75%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	9880%	1068%	7984%	1060%	9015%	974%	7809%	961%	9015%	974%	7809%	961%
Carp	772%	4%	873%	45%	1344%	70%	1671%	136%	946%	26%	1092%	69%
Largescale sucker	1821%	121%	2195%	216%	1884%	138%	2093%	211%	1884%	138%	2093%	211%
Chinook	14080%	1601%	10069%	1406%	15993%	1822%	11943%	1583%	15993%	1822%	11943%	1583%
Sculpin	2373%	190%	1733%	162%	2990%	273%	2220%	235%	3749%	359%	2920%	321%
Peamouth	15255%	1691%	15560%	2100%	8542%	936%	9564%	1262%	32749%	3819%	33930%	4643%
Black crappie	24141%	2724%	20563%	2826%	55380%	6570%	54639%	7689%	46066%	5398%	41641%	5685%
Brown bullhead	4602%	455%	3499%	413%	4407%	433%	4036%	462%	8154%	885%	6309%	794%
Smallmouth bass	4964%	490%	4935%	609%	6156%	652%	6005%	770%	9843%	1085%	9592%	1244%
Northern pikeminnow	10570%	1149%	11503%	1546%	6992%	750%	6832%	879%	23281%	2687%	25148%	3410%
Mean RPD	8132%	866%	7242%	948%	10375%	1156%	9795%	1297%	13918%	1572%	13038%	1727%
Median RPD	4964%	490%	4935%	609%	6156%	652%	6005%	770%	9015%	974%	7809%	961%
Number RPDs less than 100%	0/11	2/11	0/11	2/11	0/11	2/11	0/11	1/11	0/11	2/11	0/11	2/11
Number RPDs less than 400%	0/11	4/11	0/11	4/11	0/11	4/11	0/11	4/11	0/11	4/11	0/11	4/11

na – not applicable
RPD – relative percent difference

Comparison to median concentrations of total PCBs (µg/kg ww) as relative percent difference (RPD)												
Scenario	**3j**	**3l**	**3i**	**3k**	**4j**	**4l**	**4i**	**4k**	**1j**	**1l**	**1i**	**1k**
Mollusk	1123%	54%	853%	60%	1602%	116%	1059%	95%	1602%	116%	1059%	95%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	48240%	5558%	39056%	5518%	44053%	5105%	38207%	5037%	44053%	5105%	38207%	5037%
Carp	1580%	101%	1775%	179%	2682%	227%	3313%	355%	1915%	142%	2198%	226%
Largescale sucker	2813%	235%	3381%	379%	2909%	261%	3226%	371%	2909%	261%	3226%	371%
Chinook	14080%	1601%	10069%	1406%	15993%	1822%	11943%	1583%	15993%	1822%	11943%	1583%
Sculpin	5124%	512%	3772%	453%	6429%	688%	4803%	609%	8033%	870%	6282%	789%
Peamouth	17735%	1980%	18089%	2455%	9937%	1103%	11125%	1482%	38053%	4452%	39426%	5409%
Black crappie	32383%	3684%	27588%	3821%	74243%	8837%	73250%	10338%	61762%	7267%	55834%	7652%
Brown bullhead	14741%	1650%	11260%	1520%	14126%	1582%	12954%	1674%	25952%	3009%	20128%	2721%
Smallmouth bass	7126%	743%	7084%	912%	8827%	974%	8612%	1142%	14088%	1590%	13729%	1818%
Northern pikeminnow	12782%	1408%	13908%	1887%	8462%	927%	8268%	1082%	28127%	3265%	30381%	4138%
Mean RPD	14339%	1593%	12440%	1690%	17206%	1967%	16069%	2161%	22044%	2536%	20219%	2713%
Median RPD	12782%	1408%	10069%	1406%	8827%	974%	8612%	1142%	15993%	1822%	13729%	1818%
Number RPDs less than 100%	0/11	1/11	0/11	1/11	0/11	0/11	0/11	1/11	0/11	0/11	0/11	1/11
Number RPDs less than 400%	0/11	3/11	0/11	3/11	0/11	3/11	0/11	3/11	0/11	3/11	0/11	3/11
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as relative percent difference (RPD)												
Mollusk	1035%	43%	784%	49%	1479%	100%	975%	81%	1479%	100%	975%	81%
Oligochaete	na	na	na	na	na	na	na	na	na	na	na	na
Insect	na	na	na	na	na	na	na	na	na	na	na	na
Amphipod	na	na	na	na	na	na	na	na	na	na	na	na
Crayfish	25682%	2917%	20783%	2896%	23448%	2676%	20330%	2640%	23448%	2676%	20330%	2640%
Carp	1606%	104%	1804%	184%	2725%	232%	3366%	362%	1946%	146%	2234%	231%
Largescale sucker	2874%	242%	3453%	389%	2971%	269%	3295%	381%	2971%	269%	3295%	381%
Chinook	15470%	1768%	11066%	1553%	17570%	2011%	13123%	1748%	17570%	2011%	13123%	1748%
Sculpin	4284%	413%	3149%	364%	5379%	561%	4014%	495%	6724%	714%	5255%	646%
Peamouth	15942%	1771%	16260%	2198%	8928%	982%	9996%	1323%	34217%	3994%	35451%	4855%
Black crappie	26970%	3053%	22973%	3167%	61853%	7348%	61025%	8598%	51452%	6039%	46511%	6360%
Brown bullhead	9743%	1061%	7434%	974%	9335%	1016%	8557%	1076%	17178%	1962%	13316%	1771%
Smallmouth bass	7794%	820%	7748%	1006%	9653%	1073%	9417%	1256%	15400%	1747%	15008%	1996%
Northern pikeminnow	12228%	1343%	13306%	1801%	8094%	883%	7908%	1031%	26913%	3120%	29070%	3955%
Mean RPD	11239%	1231%	9887%	1326%	13767%	1559%	12910%	1727%	18118%	2071%	16779%	2242%
Median RPD	9743%	1061%	7748%	1006%	8928%	982%	8557%	1076%	17178%	1962%	13316%	1771%
Number RPDs less than 100%	0/11	1/11	0/11	1/11	0/11	0/11	0/11	1/11	0/11	0/11	0/11	1/11
Number RPDs less than 400%	0/11	3/11	0/11	4/11	0/11	3/11	0/11	3/11	0/11	3/11	0/11	3/11

na – not applicable
RPD – relative percent difference

Appendix D - Summary output for TrophicTrace model

Predicted concentration of total PCBs (μg/kg ww)								
Scenario	**1a**	**1b**	**1c**	**1d**	**1e**	**1f**	**1g**	**1h**
Black crappie	670	419	822	567	647	354	769	477
Brown bullhead	715	411	863	554	731	363	854	486
Carp	541	448	708	614	473	366	608	501
Largescale sucker	546	431	707	590	488	355	617	485
Northern pikeminnow	1062	574	1267	772	913	415	1050	552
Peamouth	807	444	966	598	760	359	880	479
Sculpin	683	365	813	491	728	333	839	443
Smallmouth bass	1002	528	1189	709	894	397	1024	527
Comparison to mean concentrations of total PCBs (μg/kg ww) as RPD								
Black crappie	400%	212%	514%	323%	383%	164%	474%	256%
Brown bullhead	77%	2%	114%	37%	81%	-10%	111%	20%
Carp	-67%	-73%	-57%	-63%	-71%	-78%	-63%	-69%
Largescale sucker	-33%	-47%	-14%	-28%	-40%	-57%	-25%	-41%
Northern pikeminnow	27%	-31%	52%	-7%	10%	-50%	26%	-34%
Peamouth	332%	138%	417%	220%	307%	92%	371%	156%
Sculpin	21%	-35%	45%	-13%	30%	-41%	49%	-21%
Smallmouth bass	-10%	-53%	7%	-36%	-20%	-64%	-8%	-53%
Mean RPD	93%	14%	135%	54%	85%	-5%	117%	27%
Median RPD	24%	-33%	48%	-10%	20%	-46%	38%	-27%
Number RPDs less than 100%	6/8	6/8	5/8	6/8	6/8	7/8	5/8	6/8
Number RPDs less than 400%	7/8	8/8	6/8	8/8	8/8	8/8	7/8	8/8
Comparison to median concentrations of total PCBs (μg/kg ww) as RPD								
Black crappie	570%	319%	722%	467%	547%	254%	669%	377%
Brown bullhead	459%	221%	574%	333%	471%	183%	567%	280%
Carp	-36%	-47%	-17%	-28%	-44%	-57%	-29%	-41%
Largescale sucker	1%	-20%	31%	9%	-10%	-34%	14%	-10%
Northern pikeminnow	54%	-17%	84%	12%	32%	-40%	52%	-20%
Peamouth	401%	176%	500%	272%	372%	123%	447%	198%
Sculpin	157%	37%	206%	85%	174%	25%	215%	66%
Smallmouth bass	28%	-32%	52%	-9%	15%	-49%	31%	-32%
Mean RPD	204%	80%	269%	143%	195%	51%	246%	102%
Median RPD	105%	10%	145%	48%	103%	-5%	134%	28%
Number RPDs less than 100%	4/8	5/8	4/8	5/8	4/8	5/8	4/8	5/8
Number RPDs less than 400%	5/8	8/8	5/8	7/8	6/8	8/8	5/8	8/8
Comparison to geometric mean concentrations of total PCBs (μg/kg ww) as RPD								
Black crappie	458%	249%	585%	373%	439%	195%	541%	297%
Brown bullhead	271%	113%	347%	187%	279%	88%	342%	152%
Carp	-35%	-46%	-15%	-27%	-44%	-56%	-27%	-40%
Largescale sucker	3%	-18%	34%	12%	-8%	-33%	17%	-8%
Northern pikeminnow	47%	-20%	76%	7%	27%	-42%	46%	-23%
Peamouth	351%	148%	440%	234%	325%	101%	392%	168%
Sculpin	115%	15%	156%	55%	130%	5%	165%	40%
Smallmouth bass	40%	-26%	67%	-1%	25%	-44%	43%	-26%
Mean RPD	156%	52%	211%	105%	147%	27%	190%	70%
Median RPD	81%	-2%	116%	33%	78%	-14%	105%	16%
Number RPDs less than 100%	4/8	5/8	4/8	5/8	4/8	6/8	4/8	5/8
Number RPDs less than 400%	7/8	8/8	6/8	8/8	7/8	8/8	7/8	8/8
Comparison to maximum concentrations of total PCBs (μg/kg ww) as RPD								
Black crappie	168%	67%	229%	127%	159%	42%	208%	91%
Brown bullhead	-58%	-76%	-49%	-67%	-57%	-79%	-50%	-71%
Carp	-92%	-93%	-89%	-91%	-93%	-94%	-91%	-92%
Largescale sucker	-73%	-79%	-65%	-71%	-76%	-82%	-69%	-76%
Northern pikeminnow	-41%	-68%	-30%	-57%	-49%	-77%	-42%	-69%
Peamouth	178%	53%	233%	106%	162%	24%	204%	65%
Sculpin	-80%	-89%	-76%	-85%	-78%	-90%	-75%	-87%
Smallmouth bass	-78%	-88%	-74%	-84%	-80%	-91%	-77%	-88%
Mean RPD	-9%	-47%	10%	-28%	-14%	-56%	1%	-41%
Median RPD	-65%	-77%	-57%	-69%	-66%	-81%	-60%	-74%
Number RPDs less than 100%	6/8	8/8	6/8	6/8	6/8	8/8	6/8	8/8
Number RPDs less than 400%	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8

na – not applicable

RPD – relative percent difference

Predicted concentration of total PCBs (µg/kg ww)				
Scenario	**2a**	**2b**	**2c**	**2d**
Black crappie	907	400	2890	530
Brown bullhead	717	339	2100	436
Carp	599	506	520	414
Largescale sucker	1120	768	2880	813
Northern pikeminnow	1040	478	2640	522
Peamouth	837	342	2750	471
Sculpin	769	313	2530	453
Smallmouth bass	1160	529	3090	598
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD				
Black crappie	577%	198%	2054%	295%
Brown bullhead	78%	-16%	420%	8%
Carp	-63%	-69%	-68%	-75%
Largescale sucker	36%	-6%	252%	-1%
Northern pikeminnow	25%	-43%	217%	-37%
Peamouth	348%	83%	1368%	152%
Sculpin	37%	-44%	351%	-19%
Smallmouth bass	4%	-52%	178%	-46%
Mean RPD	130%	6%	596%	35%
Median RPD	37%	-29%	301%	-10%
Number RPDs less than 100%	6/8	7/8	1/8	6/8
Number RPDs less than 400%	7/8	8/8	5/8	8/8
Comparison to median concentrations of total PCBs (µg/kg ww) as RPD				
Black crappie	807%	300%	2786%	430%
Brown bullhead	460%	165%	1540%	241%
Carp	-29%	-40%	-39%	-51%
Largescale sucker	107%	42%	434%	50%
Northern pikeminnow	51%	-31%	283%	-24%
Peamouth	420%	112%	1606%	192%
Sculpin	189%	18%	852%	70%
Smallmouth bass	48%	-32%	296%	-23%
Mean RPD	257%	67%	970%	111%
Median RPD	148%	30%	643%	60%
Number RPDs less than 100%	3/8	5/8	1/8	5/8
Number RPDs less than 400%	5/8	8/8	3/8	7/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD				
Black crappie	656%	233%	2305%	341%
Brown bullhead	272%	76%	988%	126%
Carp	-28%	-39%	-38%	-51%
Largescale sucker	111%	45%	445%	54%
Northern pikeminnow	44%	-34%	266%	-28%
Peamouth	368%	91%	1434%	163%
Sculpin	143%	-1%	699%	43%
Smallmouth bass	62%	-26%	333%	-16%
Mean RPD	203%	43%	804%	79%
Median RPD	127%	22%	572%	48%
Number RPDs less than 100%	3/8	7/8	1/8	5/8
Number RPDs less than 400%	7/8	8/8	3/8	8/8
Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD				
Black crappie	263%	60%	1054%	112%
Brown bullhead	-58%	-80%	23%	-74%
Carp	-91%	-92%	-92%	-94%
Largescale sucker	-45%	-62%	43%	-60%
Northern pikeminnow	-42%	-73%	47%	-71%
Peamouth	189%	18%	847%	62%
Sculpin	-77%	-91%	-25%	-87%
Smallmouth bass	-74%	-88%	-31%	-87%
Mean RPD	8%	-51%	233%	-37%
Median RPD	-51%	-77%	33%	-73%
Number RPDs less than 100%	6/8	8/8	6/8	7/8
Number RPDs less than 400%	8/8	8/8	6/8	8/8

na – not applicable

RPD – relative percent difference

Predicted concentration of total PCBs (µg/kg ww)								
Scenario	**3a**	**3b**	**3c**	**3d**	**3e**	**3f**	**3g**	**3h**
Black crappie	881	292	976	379	3337	485	3408	555
Brown bullhead	673	247	756	323	2341	381	2407	448
Carp	472	379	613	519	417	310	530	424
Largescale sucker	1057	674	1303	914	3112	763	3307	959
Northern pikeminnow	1017	417	1160	551	2838	500	2934	596
Peamouth	800	258	883	334	3001	430	3062	491
Sculpin	731	242	810	314	2751	414	2814	477
Smallmouth bass	1177	398	1308	517	4058	585	4141	668
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	557%	118%	628%	183%	2391%	262%	2443%	314%
Brown bullhead	67%	-39%	87%	-20%	479%	-6%	496%	11%
Carp	-71%	-77%	-63%	-68%	-75%	-81%	-68%	-74%
Largescale sucker	29%	-18%	59%	12%	280%	-7%	304%	17%
Northern pikeminnow	22%	-50%	39%	-34%	241%	-40%	252%	-28%
Peamouth	328%	38%	372%	79%	1505%	130%	1537%	163%
Sculpin	30%	-57%	44%	-44%	389%	-26%	401%	-15%
Smallmouth bass	6%	-64%	17%	-54%	265%	-47%	272%	-40%
Mean RPD	121%	-19%	148%	7%	684%	23%	705%	43%
Median RPD	30%	-44%	52%	-27%	335%	-17%	352%	-2%
Number RPDs less than 100%	6/8	7/8	6/8	7/8	1/8	6/8	1/8	6/8
Number RPDs less than 400%	7/8	8/8	7/8	8/8	5/8	8/8	4/8	8/8
Comparison to median concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	781%	192%	876%	279%	3237%	385%	3308%	455%
Brown bullhead	426%	93%	491%	153%	1729%	198%	1781%	250%
Carp	-44%	-55%	-28%	-39%	-51%	-63%	-38%	-50%
Largescale sucker	96%	25%	141%	69%	476%	41%	512%	78%
Northern pikeminnow	47%	-40%	68%	-20%	311%	-28%	325%	-14%
Peamouth	397%	60%	449%	108%	1764%	167%	1802%	205%
Sculpin	175%	-9%	205%	18%	934%	56%	958%	80%
Smallmouth bass	51%	-49%	68%	-34%	420%	-25%	431%	-14%
Mean RPD	241%	27%	284%	67%	1103%	91%	1135%	124%
Median RPD	135%	8%	173%	44%	705%	48%	735%	79%
Number RPDs less than 100%	4/8	7/8	3/8	5/8	1/8	5/8	1/8	5/8
Number RPDs less than 400%	6/8	8/8	5/8	8/8	2/8	8/8	2/8	7/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	634%	143%	713%	216%	2681%	304%	2740%	363%
Brown bullhead	249%	28%	292%	68%	1113%	98%	1147%	132%
Carp	-44%	-55%	-27%	-38%	-50%	-63%	-37%	-49%
Largescale sucker	100%	27%	146%	73%	488%	44%	525%	81%
Northern pikeminnow	41%	-42%	61%	-24%	294%	-31%	307%	-17%
Peamouth	347%	44%	394%	87%	1577%	140%	1611%	174%
Sculpin	131%	-24%	156%	-1%	768%	31%	788%	51%
Smallmouth bass	65%	-44%	83%	-28%	468%	-18%	480%	-6%
Mean RPD	190%	10%	227%	44%	917%	63%	945%	91%
Median RPD	115%	2%	151%	33%	628%	37%	657%	66%
Number RPDs less than 100%	4/8	7/8	3/8	7/8	1/8	6/8	1/8	5/8
Number RPDs less than 400%	7/8	8/8	7/8	8/8	2/8	8/8	2/8	8/8
Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	252%	17%	290%	52%	1235%	94%	1263%	122%
Brown bullhead	-60%	-85%	-56%	-81%	38%	-78%	42%	-74%
Carp	-93%	-94%	-91%	-92%	-94%	-95%	-92%	-93%
Largescale sucker	-48%	-67%	-36%	-55%	54%	-62%	64%	-53%
Northern pikeminnow	-43%	-77%	-36%	-69%	58%	-72%	63%	-67%
Peamouth	176%	-11%	205%	15%	935%	48%	956%	69%
Sculpin	-78%	-93%	-76%	-91%	-18%	-88%	-16%	-86%
Smallmouth bass	-74%	-91%	-71%	-89%	-10%	-87%	-8%	-85%
Mean RPD	4%	-63%	16%	-51%	275%	-42%	284%	-33%
Median RPD	-54%	-81%	-46%	-75%	46%	-75%	52%	-70%
Number RPDs less than 100%	6/8	8/8	6/8	8/8	6/8	8/8	6/8	7/8
Number RPDs less than 400%	8/8	8/8	8/8	8/8	6/8	8/8	6/8	8/8

na – not applicable

RPD – relative percent difference

Predicted concentration of total PCBs (µg/kg ww)								
Scenario	**4a**	**4b**	**4c**	**4d**	**4e**	**4f**	**4g**	**4h**
Black crappie	1066	571	1263	768	952	428	1094	569
Brown bullhead	473	318	587	433	473	285	574	385
Carp	455	360	588	493	402	295	510	403
Largescale sucker	548	431	707	590	488	355	617	485
Northern pikeminnow	815	474	981	641	736	372	863	498
Peamouth	583	404	729	550	541	336	660	456
Sculpin	719	410	862	553	753	373	879	499
Smallmouth bass	1078	589	1282	793	948	437	1093	582
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	695%	326%	842%	473%	611%	219%	716%	325%
Brown bullhead	17%	-21%	45%	7%	17%	-29%	42%	-5%
Carp	-72%	-78%	-64%	-70%	-75%	-82%	-69%	-75%
Largescale sucker	-33%	-47%	-14%	-28%	-40%	-57%	-25%	-41%
Northern pikeminnow	-2%	-43%	18%	-23%	-12%	-55%	4%	-40%
Peamouth	212%	116%	290%	194%	189%	80%	253%	144%
Sculpin	28%	-27%	53%	-2%	34%	-34%	56%	-11%
Smallmouth bass	-3%	-47%	15%	-29%	-15%	-61%	-2%	-48%
Mean RPD	105%	22%	148%	65%	89%	-2%	122%	31%
Median RPD	7%	-35%	32%	-12%	3%	-45%	23%	-26%
Number RPDs less than 100%	6/8	6/8	6/8	6/8	6/8	7/8	6/8	6/8
Number RPDs less than 400%	7/8	8/8	7/8	7/8	7/8	8/8	7/8	8/8
Comparison to median concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	373%	471%	1163%	668%	852%	328%	994%	469%
Brown bullhead	269%	149%	359%	238%	270%	123%	348%	201%
Carp	-47%	-58%	-31%	-42%	-53%	-65%	-40%	-53%
Largescale sucker	1%	-20%	31%	9%	-10%	-34%	14%	-10%
Northern pikeminnow	18%	-31%	42%	-7%	7%	-46%	25%	-28%
Peamouth	262%	151%	353%	242%	236%	109%	310%	183%
Sculpin	170%	54%	224%	108%	183%	40%	230%	87%
Smallmouth bass	38%	-24%	64%	2%	22%	-44%	40%	-25%
Mean RPD	136%	86%	276%	152%	188%	51%	240%	103%
Median RPD	104%	17%	144%	59%	102%	3%	135%	39%
Number RPDs less than 100%	4/8	5/8	4/8	4/8	4/8	5/8	4/8	5/8
Number RPDs less than 400%	8/8	7/8	7/8	7/8	7/8	8/8	7/8	7/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	294%	376%	952%	540%	694%	257%	811%	374%
Brown bullhead	145%	65%	204%	124%	145%	48%	197%	100%
Carp	-46%	-57%	-30%	-41%	-52%	-65%	-39%	-52%
Largescale sucker	4%	-18%	34%	12%	-8%	-33%	17%	-8%
Northern pikeminnow	13%	-34%	36%	-11%	2%	-48%	20%	-31%
Peamouth	226%	126%	307%	207%	202%	88%	269%	155%
Sculpin	127%	29%	172%	74%	138%	18%	177%	57%
Smallmouth bass	51%	-18%	80%	11%	33%	-39%	53%	-19%
Mean RPD	102%	59%	219%	115%	144%	28%	188%	72%
Median RPD	89%	6%	126%	43%	85%	-8%	115%	24%
Number RPDs less than 100%	4/8	6/8	4/8	5/8	4/8	7/8	4/8	6/8
Number RPDs less than 400%	8/8	8/8	7/8	7/8	7/8	8/8	7/8	8/8
Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	89%	128%	405%	207%	281%	71%	337%	128%
Brown bullhead	-72%	-81%	-65%	-75%	-72%	-83%	-66%	-77%
Carp	-93%	-94%	-91%	-92%	-94%	-95%	-92%	-94%
Largescale sucker	-73%	-79%	-65%	-71%	-76%	-82%	-69%	-76%
Northern pikeminnow	-55%	-74%	-45%	-64%	-59%	-79%	-52%	-72%
Peamouth	101%	39%	152%	90%	86%	16%	128%	57%
Sculpin	-79%	-88%	-74%	-84%	-78%	-89%	-74%	-85%
Smallmouth bass	-76%	-87%	-72%	-82%	-79%	-90%	-76%	-87%
Mean RPD	-32%	-42%	18%	-21%	-11%	-54%	4%	-38%
Median RPD	-73%	-80%	-65%	-73%	-74%	-83%	-68%	-77%
Number RPDs less than 100%	7/8	7/8	6/8	7/8	7/8	8/8	6/8	7/8
Number RPDs less than 400%	8/8	8/8	7/8	8/8	8/8	8/8	8/8	8/8

na – not applicable

RPD – relative percent difference

Predicted concentration of total PCBs (µg/kg ww)						
Scenario	**5a**	**5b**	**5c**	**5d**		
Black crappie	1331	850	1624	684		
Brown bullhead	632	499	625	453		
Carp	682	527	1093	478		
Largescale sucker	709	558	912	487		
Northern pikeminnow	1090	669	2632	695		
Peamouth	398	169	823	185		
Sculpin	1031	778	1118	711		
Smallmouth bass	1353	877	1638	699		
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD						
Black crappie	893%	534%	1112%	410%		
Brown bullhead	57%	24%	55%	12%		
Carp	-58%	-68%	-33%	-71%		
Largescale sucker	-13%	-32%	11%	-41%		
Northern pikeminnow	31%	-20%	216%	-17%		
Peamouth	113%	-10%	340%	-1%		
Sculpin	83%	38%	99%	27%		
Smallmouth bass	22%	-21%	47%	-37%		
Mean RPD	141%	56%	231%	35%		
Median RPD	44%	-15%	77%	-9%		
Number RPDs less than 100%	6/8	7/8	5/8	7/8		
Number RPDs less than 400%	7/8	7/8	7/8	7/8		
Comparison to median concentrations of total PCBs (µg/kg ww) as RPD						
Black crappie	1231%	750%	1524%	584%		
Brown bullhead	394%	290%	388%	254%		
Carp	-20%	-38%	29%	-44%		
Largescale sucker	31%	3%	69%	-10%		
Northern pikeminnow	58%	-3%	281%	1%		
Peamouth	147%	5%	411%	15%		
Sculpin	288%	192%	320%	167%		
Smallmouth bass	73%	12%	110%	-10%		
Mean RPD	275%	151%	392%	120%		
Median RPD	110%	9%	301%	8%		
Number RPDs less than 100%	4/8	5/8	2/8	5/8		
Number RPDs less than 400%	7/8	7/8	6/8	7/8		
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD						
Black crappie	1009%	608%	1253%	470%		
Brown bullhead	228%	159%	224%	135%		
Carp	-19%	-37%	31%	-43%		
Largescale sucker	34%	6%	72%	-8%		
Northern pikeminnow	51%	-7%	265%	-4%		
Peamouth	122%	-6%	360%	3%		
Sculpin	225%	145%	253%	124%		
Smallmouth bass	89%	23%	129%	-2%		
Mean RPD	218%	111%	323%	84%		
Median RPD	106%	14%	238%	1%		
Number RPDs less than 100%	4/8	5/8	2/8	5/8		
Number RPDs less than 400%	7/8	7/8	7/8	7/8		
Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD						
Black crappie	432%	240%	550%	174%		
Brown bullhead	-63%	-71%	-63%	-73%		
Carp	-90%	-92%	-83%	-93%		
Largescale sucker	-65%	-72%	-55%	-76%		
Northern pikeminnow	-39%	-63%	46%	-61%		
Peamouth	37%	-42%	184%	-36%		
Sculpin	-69%	-77%	-67%	-79%		
Smallmouth bass	-70%	-81%	-64%	-84%		
Mean RPD	9%	-32%	56%	-41%		
Median RPD	-64%	-71%	-59%	-75%		
Number RPDs less than 100%	7/8	7/8	6/8	7/8		
Number RPDs less than 400%	7/8	8/8	7/8	8/8		

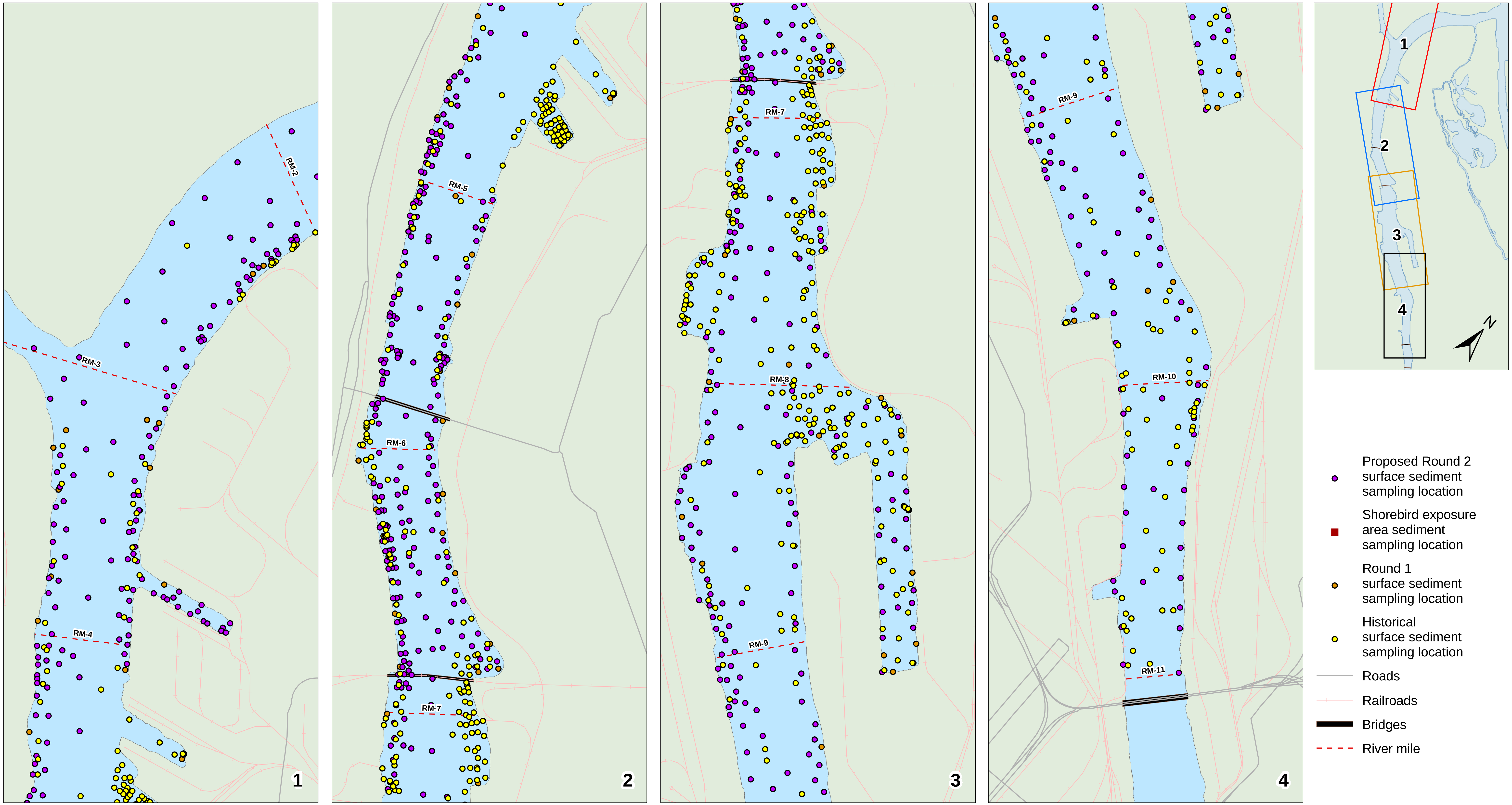
na – not applicable

RPD – relative percent difference

Predicted concentration of total PCBs (µg/kg ww)								
Scenario	**6a**	**6b**	**6c**	**6d**	**6e**	**6f**	**6g**	**6h**
Black crappie	1274	747	1536	1010	1714	622	1906	814
Brown bullhead	586	199	646	259	2813	396	2867	449
Carp	447	228	525	305	1407	284	1470	347
Largescale sucker	498	310	608	419	1030	312	1120	401
Northern pikeminnow	1045	596	1253	804	2710	648	2873	811
Peamouth	360	125	398	163	813	152	844	183
Sculpin	1010	743	1281	1014	1142	684	1383	925
Smallmouth bass	1293	771	1565	1043	1730	636	1927	833
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	850%	458%	1046%	654%	1179%	364%	1322%	507%
Brown bullhead	45%	-51%	60%	-36%	596%	-2%	610%	11%
Carp	-73%	-86%	-68%	-81%	-14%	-83%	-10%	-79%
Largescale sucker	-39%	-62%	-26%	-49%	26%	-62%	37%	-51%
Northern pikeminnow	25%	-28%	50%	-4%	225%	-22%	245%	-3%
Peamouth	93%	-33%	113%	-13%	335%	-19%	351%	-2%
Sculpin	80%	32%	128%	80%	103%	22%	146%	65%
Smallmouth bass	16%	-31%	41%	-6%	55%	-43%	73%	-25%
Mean RPD	125%	25%	168%	68%	313%	19%	347%	53%
Median RPD	35%	-32%	55%	-9%	164%	-21%	196%	-2%
Number RPDs less than 100%	7/8	7/8	5/8	7/8	3/8	7/8	3/8	7/8
Number RPDs less than 400%	7/8	7/8	7/8	7/8	6/8	8/8	6/8	7/8
Comparison to median concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	1174%	647%	1436%	910%	1614%	522%	1806%	714%
Brown bullhead	358%	56%	405%	103%	2098%	209%	2140%	251%
Carp	-47%	-73%	-38%	-64%	66%	-67%	73%	-59%
Largescale sucker	-8%	-43%	13%	-22%	91%	-42%	107%	-26%
Northern pikeminnow	51%	-14%	82%	16%	293%	-6%	316%	18%
Peamouth	124%	-22%	147%	1%	405%	-6%	424%	14%
Sculpin	280%	179%	382%	281%	329%	157%	420%	248%
Smallmouth bass	66%	-1%	101%	34%	122%	-19%	147%	7%
Mean RPD	250%	91%	316%	157%	627%	94%	679%	146%
Median RPD	95%	-7%	124%	25%	311%	-6%	368%	16%
Number RPDs less than 100%	4/8	6/8	3/8	5/8	2/8	5/8	1/8	5/8
Number RPDs less than 400%	7/8	7/8	6/8	7/8	5/8	7/8	4/8	7/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	961%	523%	1180%	741%	1328%	418%	1488%	578%
Brown bullhead	204%	3%	235%	34%	1358%	105%	1385%	133%
Carp	-47%	-73%	-37%	-64%	68%	-66%	76%	-59%
Largescale sucker	-6%	-41%	15%	-21%	95%	-41%	112%	-24%
Northern pikeminnow	45%	-17%	74%	11%	276%	-10%	299%	12%
Peamouth	101%	-30%	122%	-9%	354%	-15%	371%	2%
Sculpin	219%	134%	304%	220%	260%	116%	336%	192%
Smallmouth bass	81%	8%	119%	46%	142%	-11%	170%	17%
Mean RPD	195%	63%	252%	120%	485%	62%	530%	106%
Median RPD	91%	-7%	121%	23%	268%	-11%	317%	15%
Number RPDs less than 100%	4/8	6/8	3/8	6/8	2/8	5/8	1/8	5/8
Number RPDs less than 400%	7/8	7/8	7/8	7/8	6/8	7/8	6/8	7/8
Comparison to maximum concentrations of total PCBs (µg/kg ww) as RPD								
Black crappie	409%	199%	514%	304%	585%	149%	662%	226%
Brown bullhead	-66%	-88%	-62%	-85%	65%	-77%	69%	-74%
Carp	-93%	-96%	-92%	-95%	-78%	-96%	-77%	-95%
Largescale sucker	-75%	-85%	-70%	-79%	-49%	-85%	-45%	-80%
Northern pikeminnow	-42%	-67%	-30%	-55%	51%	-64%	60%	-55%
Peamouth	24%	-57%	37%	-44%	180%	-48%	191%	-37%
Sculpin	-70%	-78%	-62%	-70%	-66%	-80%	-59%	-72%
Smallmouth bass	-71%	-83%	-65%	-77%	-62%	-86%	-57%	-81%
Mean RPD	2%	-44%	21%	-25%	78%	-48%	93%	-34%
Median RPD	-68%	-80%	-62%	-73%	1%	-78%	8%	-73%
Number RPDs less than 100%	7/8	7/8	7/8	7/8	6/8	7/8	6/8	7/8
Number RPDs less than 400%	7/8	8/8	7/8	8/8	7/8	8/8	7/8	8/8

na – not applicable

RPD – relative percent difference



Windward environmental LLC

0 1,000 2,000 4,000 Feet
0 260 520 1,040 Meters

Prepared by RAC 05/12/04 Map 1358

Figure 3-1. Historical, Round 1, and proposed Round 2 surface sediment and ERA beach sediment sampling locations

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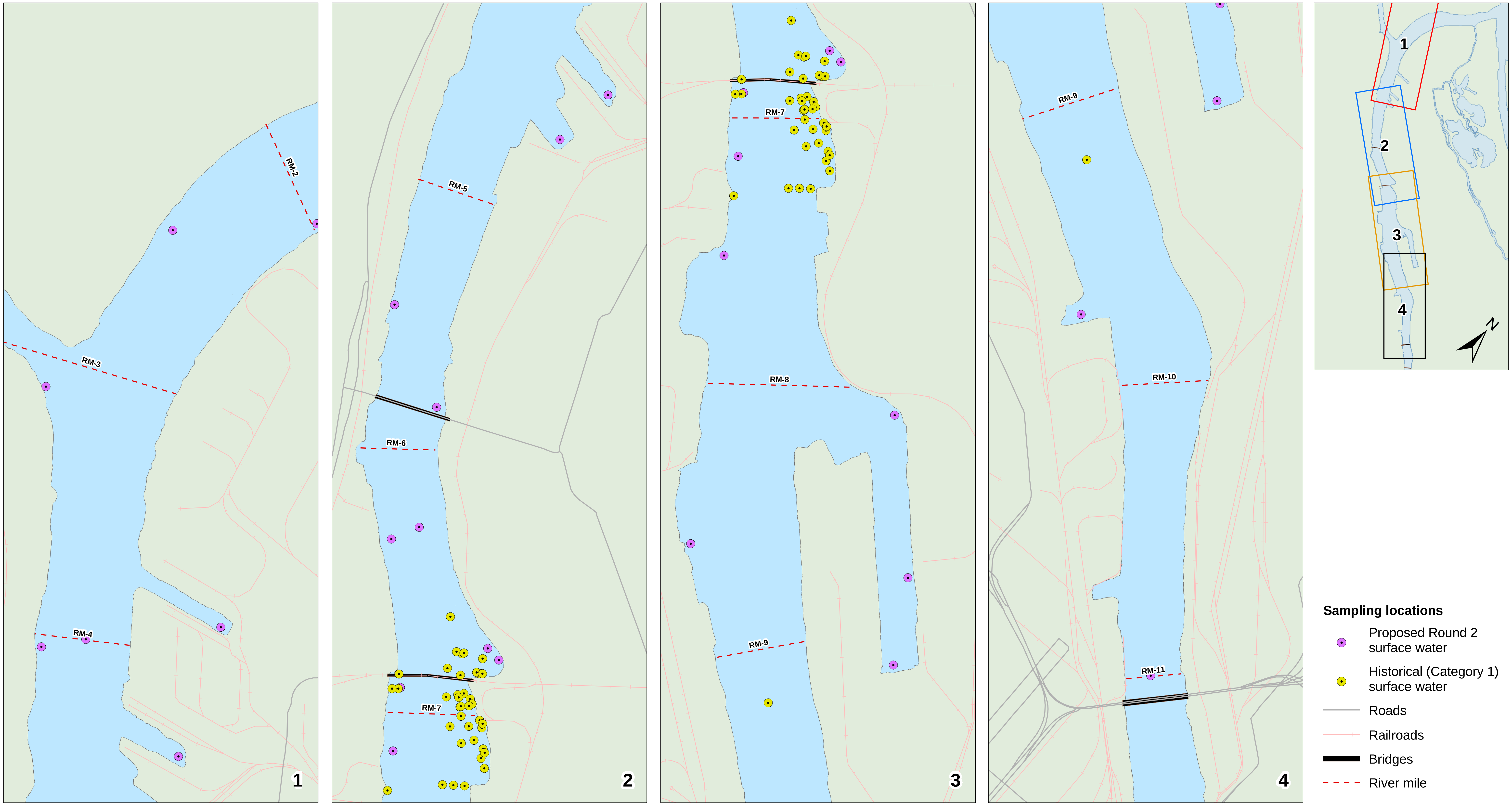

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Prepared by RAC 05/12/04 Map 1353

0 1,000 2,000 4,000 Feet

0 260 520 1,040 Meters

Figure 3-2. Historical and proposed Round 2 surface water sampling locations

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Table 3-1. Lipid content, weight, and PCB concentrations for fish and invertebrate species

Common Name	Latin Name	Lipid Content (%)	Weight (kg)	Mean Total PCB Conc. (µg/kg ww)	Median Total PCB Conc. (µg/kg ww)	Geometric Mean Total PCB Conc. (µg/kg ww)	Maximum Total PCB Conc. (µg/kg ww)	Number of Round 1 Samples	Reference
Fish									
Black crappie	*Pomoxis nigromaculatus*	5.3	0.221	134	100	120	250	4	Round 1 data
Brown bullhead	*Ameiurus nebulosus*	2.4	0.256	404	128	193	1700	6	Round 1 data
Common carp	*Cyprinus carpio*	7.9	2.239	1638	850	837	6,500	6	Round 1 data
Juvenile chinook salmon	*Oncorhynchus tshawytscha*	2.9	0.012	56	56	51	100	6	Round 1 data
Largescale sucker	*Catostomus macrocheilus*	7.6	0.798	819	540	529	2020	6	Round 1 data
Northern pikeminnow	*Ptychocheilus oregonensis*	5.3	0.558	833	690	721	1,800	6	Round 1 data
Peamouth	*Mylocheilus caurinus*	9.2	0.103	187	161	179	290	4	Round 1 data
Sculpin	*Cottus sp.*	4.2	0.019	562	266	317	3,360	26	Round 1 data
Smallmouth bass	*Micropterus dolomieu*	5.4	0.426	1,113	780	714	4,500	14	Round 1 data
Invertebrates									
Amphipod	*Corophium volutator*	0.8	na	na	na	na	na	na	Kraaij et al. 2001
Amphipod	*Corophium* spp.		6×10^{-6}	na	na	na	na	na	Leon 1980
Bryozoan		2	5×10^{-7}	na	na	na	na	na	Pechenik 1991
Clam	*Corbicula fluminea*	1.2	0.0001	86	77	83	120	3	Round 1 data
Crayfish	*Pacifastacus* spp.	0.8	0.0844	31	6.4	12	280	27	Round 1 data
Gastropod	*Physa* spp.	0.57	0.0110	na	na	na	na	na	NYDEC 1999
Aquatic insect	*Chironomus* spp.	1.2		na	na	na	na	na	Lyytikäinen et al. 2003
Aquatic insect	*Chironomus riparius*	na	2×10^{-5}	na	na	na	na	na	Bervoets et al. 2002
Mollusk		0.9	0.0056	na	na	na	na	na	Round 1 data; NYDEC 1999
Worm	*Limnodrilus hoffmeisteri*	8	$1.4\ 10^{-6}$	na	na	na	na	na	Millward et al. 2001
Zooplankton									
Various	zooplankton & bryozoa	1.5	5.7×10^{-8}	na	na	na	na	na	Arnot and Gobas in press
Various zooplankton	various	1	5.7×10^{-8}	na	na	na	na	na	Arnot and Gobas in press
Phytoplankton / filamentous algae									
Various	value from green algae	0.2	na	na	na	na	na	na	MacKintosh et al. 2004

na – not applicable, or data not available

Table 3-2. Site-specific values for chemical and environmental input parameters

	Campfens & MacKay	Gobas	Arnot & Gobas	TrophicTrace	Value	Source
Chemical						
Molecular weight (g/mol)	X				326	MacKay et al. 1989
		X	X		250.54	default for Arnot and Gobas (in press)
log 10 K_{OW} (unitless)	X	X	X	X	6.3	EPA's Estimated Program Interface software
	X	X	X	X	7.3	MacKay et al. 1992
Henry's Law Constant (Pa.m^3/mol)	X	X	X		12.2	MacKay et al. 1989
Log 10(K_{OC}) or log10(kd) (unitless)				X	6.20	relationship between K_{OW} and K_{OC} taken from Hawker and Connell 1988
BSAF (unitless)				X	0.87	field-collected oligochaete (Ankley et al.1992)
				X	1	BSAF for sediment modeled as an invertebrate (see Section 3.2.3)
				X	1.20	average BSAF from Round 1 data (see Table 4-1)
Total PCB concentration in water (ng/L)	X	X	X	X	400	lowest detection limit for database of historical data
	X	X	X	X	21	total PCB concentration in sediment of 509 µg/kg dw (estimated in TrophicTrace)
		X	X	X	2	McCarthy and Gale 1999
		X	X	X	0.07	McCarthy and Gale 1999
Total PCB concentration in sediment (ng/g dry weight)	X	X	X	X	509	area-weighted average concentration from all Category 1 and Round 1 ISA sediment samples (see Figure 3-2)
		X	X	X	479	area-weighted average concentration from all Category 1 and Round 1 ISA sediment samples from less than 20 ft depth
Environmental						
Mean water temperature (°C)		X	X	X	15	historical data in database
DOC content (kg/L)		X	X	X	1.83×10^{-6}	derived from TOC value (ODEQ 2004) and POC/DOC ratios (Arnot and Gobas in press)
POC content (kg/L)	X	X	X	X	4.6×10^{-7}	
Concentration of suspended solids (kg/L)	X		X		1.19×10^{-5}	ODEQ 2004
Sediment organic carbon content (%)	X	X	X	X	1.56	Round 1 sediment samples
Volume fraction sediment solids (%)	X				67.9	Round 1 sediment samples
Food Web						
Metabolic transformation rate constant (kM) (day^{-1})		X	X		0	default for PCBs in Gobas 1993

	Campfens & MacKay	Gobas	Arnot & Gobas	TrophicTrace	Value	Source
Metabolism half-life (years)	X				5,000	Gobas 1993
Species name	X	X	X	X		see Table 3-1
Species weight (kg)	fish, clam and crayfish	fish only	all but phytoplankton	fish only		see Table 3-1
Species lipid content (%)	fish, clam and crayfish	all species	all species	all species		see Table 3-1
Feeding preferences/fractions	fish only	fish only	all species	fish only		see Tables 3-3 to 3-8
Dietary pathway for invertebrates (water or sediment)				X		

DOC – dissolved organic carbon
POC – particulate organic carbon
TOC – total organic carbon

Table 3-3. Food web 1 dietary preferences

Species	Black Crappie	Brown Bullhead	Juvenile Chinook Salmon	Clam	Crayfish	Carp	Largescale Sucker	Northern Pike-minnow	Peamouth	Sculpin	Small-mouth Bass
Black crappie			0.333		0.333					0.333	
Brown bullhead			0.25	0.25	0.25					0.25	
Carp				0.5	0.5						
Juvenile chinook salmon				0.5	0.5						
Largescale sucker				0.5	0.5						
Northern pikeminnow	0.125	0.125	0.125		0.125		0.125		0.125	0.125	0.125
Peamouth			0.25	0.25	0.25					0.25	
Sculpin			0.333	0.333	0.333						
Smallmouth bass	0.167	0.167	0.167		0.167				0.167	0.167	

Table 3-4. Invertebrate food webs

Species	Phyto-plankton/ Algae	Zoo-plankton and Bryozoa	Mollusk	Worm	Aquatic Insect	Amphipod	Crayfish	Sediment	Source
Zooplankton & bryozoa	1.000								Pechenik 1991
Mollusk	0.700	0.100						0.200	Pechenik 1991; Zaranko et al. 1997
Oligochaete	0.100							0.900	Pechenik 1991; Zaranko et al. 1997
Aquatic insect	0.500							0.500	Pechenik 1991; Zaranko et al. 1997
Amphipod	0.333				0.333			0.334	Pechenik 1991; Zaranko et al. 1997
Crayfish	0.142	0.143	0.143	0.143	0.143	0.143		0.143	Pechenik 1991; Evans-White et al. 2001
No sediment scenario									
Zooplankton & bryozoa	1.000							na	Pechenik 1991
Mollusk	0.900	0.100						na	Pechenik 1991; Zaranko et al. 1997
Oligochaete	1.000							na	Pechenik 1991; Zaranko et al. 1997
Aquatic insect	1.000							na	Pechenik 1991; Zaranko et al. 1997
Amphipod	0.500				0.500			na	Pechenik 1991; Zaranko et al. 1997
Crayfish	0.166	0.166	0.167	0.167	0.167	0.167		na	Pechenik 1991; Evans-White et al. 2001

Clam and crayfish only

	Phyto-plankton/ Algae	Zoo-plankton & Bryozoa	Clam	Crayfish	Source
Clam	0.900	0.100			Pechenik 1991; Zaranko et al. 1997
Crayfish	0.500		0.500		Pechenik 1991; Evans-White et al. 2001

Table 3-5. Food web 2 dietary preferences

Species	Black Crappie	Brown Bullhead	Carp	Clam	Crayfish	Juvenile Chinook Salmon	Largescale Sucker	Northern Pikeminnow	Peamouth	Sculpin	Smallmouth Bass
Black crappie					0.167	0.167				0.167	
Brown bullhead				0.143	0.143	0.143				0.143	
Carp				0.2	0.2						
Juvenile chinook salmon				0.333	0.333						
Largescale sucker				0.125	0.125						
Northern pikeminnow	0.083	0.083	0.083		0.083	0.083	0.083		0.083	0.083	0.083
Peamouth				0.111	0.111	0.111				0.111	
Sculpin				0.125	0.125	0.125					
Smallmouth bass	0.091	0.091			0.091	0.091	0.091	0.091	0.091	0.091	

(continued)

Species	Worm	Aquatic Insect	Amphipod	Bryozoan	Gastropod	Phytoplankton	Sediment
Black crappie			0.167	0.167			0.167
Brown bullhead		0.143				0.143	0.143
Carp			0.2		0.2		0.2
Juvenile chinook salmon		0.333					
Largescale sucker	0.125	0.125		0.125	0.125	0.125	0.125
Northern pikeminnow		0.083	0.083				0.083
Peamouth		0.111	0.111	0.111		0.111	0.111
Sculpin		0.125	0.125	0.125	0.125		0.125
Smallmouth bass		0.091		0.091			0.091

Table 3-6. Food web 3 dietary preferences

Species	Black Crappie	Brown Bullhead	Carp	Clam	Crayfish	Juvenile Chinook Salmon	Large-scale Sucker	Northern Pikeminnow	Peamouth	Sculpin	Small-mouth Bass
Black crappie					0.2	0.2				0.2	
Brown bullhead				0.167	0.167	0.167				0.167	
Carp				0.25	0.25						
Juvenile chinook salmon				0.333	0.333						
Largescale sucker				0.143	0.143						
Northern pikeminnow	0.091	0.091	0.091		0.091	0.091	0.091		0.091	0.091	0.091
Peamouth				0.125	0.125	0.125				0.125	
Sculpin				0.143	0.143	0.143					
Smallmouth bass	0.1	0.1			0.1	0.1	0.1	0.1	0.1	0.1	

(continued)

Species	Worm	Aquatic insect	Amphipod	Bryozoan	Gastropod	Phytoplankton
Black crappie			0.2	0.2		
Brown bullhead		0.167				0.167
Carp			0.25		0.25	
Juvenile chinook salmon		0.333				
Largescale sucker	0.143	0.143		0.143	0.143	0.143
Northern pikeminnow		0.091	0.091			
Peamouth		0.125	0.125	0.125		0.125
Sculpin		0.143	0.143	0.143	0.143	
Smallmouth bass		0.1		0.1		

Table 3-7. Food web 4 dietary preferences

Species	Black Crappie	Brown Bullhead	Carp	Clam	Crayfish	Juvenile Chinook Salmon
Black crappie [a]			0.008			0.114
Brown bullhead [b]	0.008		0.008		0.939	0.008
Carp [c]					1.0	
Juvenile chinook salmon [d]				0.5	0.5	
Largescale sucker [e]				0.5	0.5	
Northern pikeminnow [f]			0.031		0.44	0.054
Peamouth [g]				0.5	0.5	
Sculpin [h]				0.714		0.286
Smallmouth bass [i]			0.008			0.114

(continued)

Species	Largescale Sucker	Northern Pikeminnow	Peamouth	Sculpin	Smallmouth Bass
Black crappie [a]	0.189	0.075	0.083	0.531	
Brown bullhead [b]	0.008	0.008	0.008	0.008	0.008
Carp [c]					
Juvenile chinook salmon [d]					
Largescale sucker [e]					
Northern pikeminnow [f]	0.031		0.031	0.412	
Peamouth [g]					
Sculpin [h]					
Smallmouth bass [i]	0.189	0.075	0.083	0.531	

[a] Values derived from smallmouth bass literature (family Centrarchidae), Zimmermann 1999
[b] Turner 1966
[c] Froese and Pauly 2004
[d] See food web 1
[e] Jorgensen 1979
[f] Buchanan et al. 1981
[g] Gray and Dauble 2001
[h] Armstrong et al. 1995
[i] Zimmermann 1999

Table 3-8. Food web 5 dietary preferences

Species	Black Crappie	Brown Bullhead	Carp	Clams	Crayfish	Juvenile Chinook Salmon	Largescale Sucker	Northern Pikeminnow	Peamouth	Sculpin	Smallmouth Bass
Black crappie [a]			0.0076			0.1083	0.1796	0.0713	0.0789	0.5045	
Brown bullhead [b]	0.0007		0.0007		0.0855	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
Carp [c]					0.2853						
Juvenile chinook salmon [d]				0.3333	0.3333						
Largescale sucker [e]				0.0179							
Northern pikeminnow [f]			0.0171		0.2412	0.0298	0.0171		0.0171	0.2255	
Peamouth [g]											
Sculpin [h]				0.1207		0.0483					
Smallmouth bass [i]			0.0076			0.1083	0.1796	0.0713	0.0789	0.5045	

(continued)

Species	Worm	Aquatic Insect	Amphipod	Bryozoan	Gastropod	Phytoplankton	Sediment
Black crappie [a]							0.05[k]
Brown bullhead [b]		0.2164	0.1477		0.0448		0.5[k]
Carp [c]		0.0654	0.0065			0.1427	0.5[k]
Juvenile chinook salmon [d]		0.3333					
Largescale sucker [e]	0.0179	0.0179	0.2143		0.0179	0.2143	0.5[j]
Northern pikeminnow [f]	0.0587	0.285				0.0587	0.05[j]
Peamouth [g]					0.4347	0.5153	0.05[j]
Sculpin [h]	0.1328		0.3621			0.0362	0.3[j]
Smallmouth bass [i]							0.05[j]

[a] Values derived from smallmouth bass literature (family Centrarchidae), Zimmermann 1999
[b] Turner 1966
[c] Froese and Pauly 2004
[d] See food web 1
[e] Jorgensen 1979
[f] Buchanan et al. 1981
[g] Gray and Dauble 2001
[h] Armstrong et al. 1995
[i] Zimmermann 1999
[j] Windward 2004
[k] Based on comparisons to fish in equivalent feeding guilds, gut content analysis, and best professional judgment.

Table 3-9. Food web 6 dietary preferences

Species	Black Crappie	Brown Bullhead	Carp	Clam	Crayfish	Juvenile Chinook Salmon	Largescale Sucker	Northern Pikeminnow	Peamouth	Sculpin	Smallmouth Bass
Black crappie [a]			0.008			0.114	0.189	0.075	0.083	0.531	
Brown bullhead [b]	0.0014		0.0014		0.1711	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014
Carp [c]					0.5707						
Juvenile chinook salmon [d]				0.3333	0.3333						
Largescale sucker [e]				0.0357							
Northern pikeminnow [f]			0.0179		0.2538	0.0313	0.0179		0.0179	0.2374	
Peamouth [g]											
Sculpin [h]				0.1724		0.069					
Smallmouth bass [i]			0.008			0.114	0.189	0.075	0.083	0.531	

(continued)

Species	Worm	Aquatic insect	Amphipod	Bryozoan	Gastropod	Phytoplankton
Black crappie [a]						
Brown bullhead [b]		0.4328	0.2953		0.0896	
Carp [c]		0.1309	0.0131			0.2853
Juvenile chinook salmon [d]		0.3333				
Largescale sucker [e]	0.0357	0.0357	0.4286		0.0357	0.4286
Northern pikeminnow [f]	0.0618	0.3				0.0618
Peamouth [g]					0.4576	0.5424
Sculpin [h]	0.1897		0.5172			0.0517
Smallmouth bass [i]						

[a] Values derived from smallmouth bass literature (family Centrarchidae), Zimmermann 1999
[b] Turner 1966
[c] Froese and Pauly 2004
[d] See food web 1
[e] Jorgensen 1979
[f] Buchanan et al. 1981
[g] Gray and Dauble 2001
[h] Armstrong et al. 1995
[i] Zimmermann 1999

Table 3-10. Model scenarios

Food Web	Scenario	$\log_{10} K_{OW}$	BSAF	PCB Conc. in Water (ng/L)	Description
1	a	6.3	0.87	21	No preference, based on gut content and qualitative literature; sediment not included; only crayfish and clams as representative invertebrates
	b	6.3	0.87	2	
	c	6.3	1.2	21	
	d	6.3	1.2	2	
	e	7.3	0.87	21	
	f	7.3	0.87	2	
	g	7.3	1.2	21	
	h	7.3	1.2	2	
	i	6.3	na	21	
	j	7.3	na	21	
	k	6.3	na	2	
	l	7.3	na	2	
2	a	6.3	1	21	No preference, based on gut content and qualitative literature; sediment and all invertebrates included
	b	6.3	1	2	
	c	7.3	1	21	
	d	7.3	1	2	
	e	6.3	na	2	
	f	7.3	na	2	
	g	6.3	na	21	
	h	7.3	na	21	

Table 3-10. Model scenarios

Food Web	Scenario	$\log_{10} K_{OW}$	BSAF	PCB Conc. in Water (ng/L)	Description
3	a	6.3	0.87	21	No preference, based on gut content and qualitative literature; sediment not included; all invertebrates represented
	b	6.3	0.87	2	
	c	6.3	1.2	21	
	d	6.3	1.2	2	
	e	7.3	0.87	21	
	f	7.3	0.87	2	
	g	7.3	1.2	21	
	h	7.3	1.2	2	
	i	6.3	na	21	
	j	7.3	na	21	
	k	6.3	na	2	
	l	7.3	na	2	
4	a	6.3	0.87	21	Preference based on best single piece of literature for each fish species; sediment not included; only crayfish and clams as representative invertebrates
	b	6.3	0.87	2	
	c	6.3	1.2	21	
	d	6.3	1.2	2	
	e	7.3	0.87	21	
	f	7.3	0.87	2	
	g	7.3	1.2	21	
	h	7.3	1.2	2	
	i	6.3	na	21	
	j	7.3	na	21	
	k	6.3	na	2	
	l	7.3	na	2	

Table 3-10. Model scenarios

Food Web	Scenario	$\log_{10} K_{OW}$	BSAF	PCB Conc. in Water (ng/L)	Description
5	a	6.3	1	21	Preference based on best single piece of literature; sediment and all invertebrates included
	b	6.3	1	2	
	c	7.3	1	21	
	d	7.3	1	2	
	e	6.3	na	2	
	f	7.3	na	2	
	g	6.3	na	21	
	h	7.3	na	21	
6	a	6.3	0.87	21	Preference based on best single piece of literature; sediment not included; all invertebrates represented
	b	6.3	0.87	2	
	c	6.3	1.2	21	
	d	6.3	1.2	2	
	e	7.3	0.87	21	
	f	7.3	0.87	2	
	g	7.3	1.2	21	
	h	7.3	1.2	2	
	i	6.3	na	21	
	j	7.3	na	21	
	k	6.3	na	2	
	l	7.3	na	2	

na – parameter not used in this scenario

Table 3-11. Parameters evaluated during uncertainty analysis

Parameter	Original Value	New Value	Source
Total PCBs in water (ng/L)	2 or 21	400 ng/L	lowest detection limit for whole water samples from historical database
Total PCBs in water (ng/L)	2 or 21	0.070 ng/L	MacCarthy and Gale 1999; measured during high-flow deployment Jan-Feb 1998
Total PCBs in sediment (µg/kg dw)	509	479	area-weighted average concentration from all Category 1 and Round 1 ISA sediment samples from less than 20 ft depth
Oligochaete lipids (%)	8.0	1.0	Gobas 1993, Arnot and Gobas in press
NLOC (non-lipid organic carbon) for phytoplankton (%)	19.8	6.8	MacKintosh et al. 2004

Table 3-12. Parameters evaluated during sensitivity analysis

Parameter	Original Value	Original Value + 10%
Concentration total PCBs in water (ng/L)	21	23.1
Concentration total PCBs in water (ng/L)	2	2.2
Concentration total PCBs in sediment (µg/kg dw)	509	560
Sediment organic carbon (%)	1.56	1.72
Biota weights (kg)	see Table 3-13	see Table 3-13
Biota lipids (kg)	see Table 3-13	see Table 3-13

na – not applicable

Table 3-13. Original and 10% increase values for biota weights and lipid percentages

	Original Value		Original Value + 10%	
Species	Weight (kg) (avg) (measured/literature)	Lipids (%) (avg) (measured/literature)	Weight (kg) (avg)	Lipids (%) (avg)
Phytoplankton	na	0.2	na	0.22
Zooplankton	0.000000057	1	0.000000063	1.10
Zooplankton/bryozoans	0.000000057	1.5	0.000000063	1.65
Bryozoans	0.0000005	2	0.00000055	2.20
Gastropod	0.011	0.57	0.0121	0.63
Clam	0.00011	1.2	0.000121	1.30
Mollusk	0.0056	0.9	0.00616	0.99
Oligochaete	0.0000014	8	0.00000154	8.80
Aquatic Insect	0.00002	1.2	0.000022	1.32
Amphipod	0.000006	0.8	0.0000066	0.88
Crayfish	0.084	0.8	0.0924	0.86
Black crappie	0.221	5.3	0.243	5.78
Brown bullhead	0.256	2.4	0.282	2.68
Carp	2.239	7.9	2.463	8.67
Juvenile chinook salmon	0.012	2.9	0.0131	3.19
Largescale sucker	0.798	7.6	0.878	8.31
Northern pikeminnow	0.558	5.3	0.614	5.78
Peamouth	0.103	9.2	0.113	10.09
Sculpin	0.019	4.2	0.0208	4.64
Smallmouth bass	0.426	5.4	0.469	5.98

na – not applicable

Table 4-1. Site-specific BSAFs calculated for sculpin and crayfish

SPECIES	N [a]	AVERAGE	MEDIAN	RANGE	CORRELATION COEFFICIENT
Sculpin	16	2.36	1.93	0.67 - 6.68	0.80
Crayfish	12	1.20	0.83	0.029 - 4.86	0.064

[a] Number of co-located sediment and tissue samples; detected total PCB concentrations only

Table 4-2. Summary of best-performing scenarios for Campfens and MacKay fugacity model

SCENARIO	1k	4k
Comparison to mean concentrations of total PCBs (µg/kg ww)		
Mean RPD	70,949%	161,552%
Median RPD	11,882%	66,394%
Number RPDs less than 100%	0/7	1/8
Number RPDs less than 400%	2/7	2/8
Comparison to median concentrations of total PCBs (µg/kg ww)		
Mean RPD	105,880%	224,580%
Median RPD	15,485%	106,456%
Number RPDs less than 100%	0/7	1/8
Number RPDs less than 400%	1/7	2/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww)		
Mean RPD	92,655%	199,898%
Median RPD	16,926%	105,992%
Number RPDs less than 100%	0/7	1/8
Number RPDs less than 400%	2/7	2/8
Comparison to maximum concentrations of total PCBs (µg/kg ww)		
Mean RPD	33,179%	82,179%
Median RPD	2854%	22,976%
Number RPDs less than 100%	2/7	2/8
Number RPDs less than 400%	2/7	2/8

RPD – relative percent difference

Table 4-3. Summary of best-performing scenarios for Gobas model

Scenario	3k	2i	2j	4k
Comparison to mean concentrations of total PCBs (µg/kg ww)				
Mean RPD	263%	279%	430%	441%
Median RPD	158%	162%	277%	154%
Number RPDs less than 100%	2/8	2/8	1/8	2/8
Number RPDs less than 400%	6/8	6/8	5/8	6/8
Comparison to median concentrations of total PCBs (µg/kg ww)				
Mean RPD	453%	479%	722%	688%
Median RPD	323%	316%	485%	337%
Number RPDs less than 100%	1/8	1/8	1/8	1/8
Number RPDs less than 400%	5/8	5/8	3/8	5/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww)				
Mean RPD	377%	398%	600%	574%
Median RPD	317%	310%	451%	319%
Number RPDs less than 100%	1/8	1/8	1/8	1/8
Number RPDs less than 400%	5/8	5/8	4/8	6/8
Comparison to maximum concentrations of total PCBs (µg/kg ww)				
Mean RPD	44%	58%	105%	42%
Median RPD	-28%	-26%	7%	-20%
Number RPDs less than 100%	6/8	6/8	6/8	6/8
Number RPDs less than 400%	8/8	8/8	7/8	8/8

RPD – relative percent difference

Table 4-4. Summary of sensitivity and uncertainty analyses for Gobas model

	Sensitivity Analysis						Uncertainty Analysis				
	Predicted Conc. (µg/kg) for Scenario 6l	Biota Lipids	Biota Weights	Sediment OC (1.72%)	PCB Conc. in Sediment (560 µg/kg)	PCB Conc. in Water (2.2 ng/L)	NLOC for Phytoplankton (6.8%)	Oligochaete Lipids (1%)	PCB Conc. in Sediment (479 µg/kg)	PCB Conc. in Water (400 ng/L)	PCB Conc. in Water (0.07 ng/L)
Mollusk	293	323	293	267	323	293	294	294	276	294	294
Oligochaete	2,608	2,869	2,608	2,371	2,869	2,608	2,612	326	2,457	2,612	2,612
Aquatic insect	391	430	391	356	430	391	392	392	369	392	392
Amphipod	261	287	261	237	287	261	261	261	246	261	261
Crayfish	261	280	261	237	287	261	261	261	246	261	261

	Sensitivity Analysis						Uncertainty Analysis				
	Predicted Conc. (µg/kg) for Scenario 6l	**Biota Lipids**	**Biota Weights**	**Sediment OC (1.72%)**	**PCB Conc. in Sediment (560 µg/kg)**	**PCB Conc. in Water (2.2 ng/L)**	**NLOC for Phytoplankton (6.8%)**	**Oligochaete Lipids (1%)**	**PCB Conc. in Sediment (479 µg/kg)**	**PCB Conc. in Water (400 ng/L)**	**PCB Conc. in Water (0.07 ng/L)**
Carp	946	1,039	948	862	1,039	948	947	947	892	3,968	933
Largescale sucker	2,023	2,238	2,027	1,843	2,220	2,027	2,025	753	1,908	10,979	1,982
Juvenile chinook salmon	686	777	692	627	751	689	687	687	648	7,442	654
Sculpin	837	950	845	767	914	844	838	838	793	14,242	773
Peamouth	1,140	1,283	1,149	1,044	1,245	1,149	1,141	1,141	1,079	19,004	1,055
Black crappie	1,294	1,470	1,307	1,186	1,412	1,305	1,295	1,295	1,225	23,351	1,188
Brown bullhead	1,082	1,241	1,096	990	1,184	1,088	1,083	1,083	1,023	14,101	1,020
Smallmouth bass	2,343	2,665	2,367	2,143	2,562	2,358	2,345	1,906	2,216	31,990	2,202
Northern pikeminnow	3,252	3,700	3,287	2,974	3,559	3,271	3,256	2,765	3,075	40,107	3,078
Comparison of predicted concentrations of total PCBs (µg/kg ww) as RPD to predicted concentrations from each model run with the parameter change indicated above											
Mollusk	na	10%	0%	-9%	10%	0%	0%	0%	-6%	0%	0%
Oligochaete	na	10%	0%	-9%	10%	0%	0%	-87%	-6%	0%	0%
Aquatic insect	na	10%	0%	-9%	10%	0%	0%	0%	-6%	0%	0%
Amphipod	na	10%	0%	-9%	10%	0%	0%	0%	-6%	0%	0%
Crayfish	na	7%	0%	-9%	10%	0%	0%	0%	-6%	0%	0%
Carp	na	10%	0%	-9%	10%	0%	0%	0%	-6%	319%	-2%
Largescale sucker	na	11%	0%	-9%	10%	0%	0%	-63%	-6%	443%	-2%
Juvenile chinook salmon	na	13%	1%	-9%	10%	0%	0%	0%	-6%	985%	-5%
Sculpin	na	14%	1%	-8%	9%	1%	0%	0%	-5%	1,601%	-8%
Peamouth	na	13%	1%	-8%	9%	1%	0%	0%	-5%	1,567%	-8%
Black crappie	na	14%	1%	-8%	9%	1%	0%	0%	-5%	1,705%	-8%
Brown bullhead	na	15%	1%	-9%	9%	1%	0%	0%	-5%	1,203%	-6%
Smallmouth bass	na	14%	1%	-9%	9%	1%	0%	-19%	-5%	1,266%	-6%
Northern pikeminnow	na	14%	1%	-9%	9%	1%	0%	-15%	-5%	1,133%	-5%
Mean RPD	**na**	**12%**	**1%**	**-9%**	**10%**	**0%**	**0%**	**-13%**	**-6%**	**730%**	**-4%**
Median RPD	**0**	**12%**	**1%**	**-9%**	**10%**	**0%**	**0%**	**0%**	**-6%**	**714%**	**-3%**

OC – organic carbon
na – not applicable
RPD – relative percent difference

Table 4-5. Summary of best-performing scenarios for Arnot and Gobas model

SCENARIO	6l	3l	6k	3k
Comparison to mean concentrations of total PCBs (µg/kg ww)				
Mean RPD	648%	853%	935%	990%
Median RPD	217%	472%	296%	511%
Number RPDs less than 100%	2/8	1/8	1/8	1/8
Number RPDs less than 400%	7/8	3/8	4/8	3/8
Comparison to median concentrations of total PCBs (µg/kg ww)				
Mean RPD	978%	1,289%	1,362%	1,451%
Median RPD	388%	1,075%	577%	1,216%
Number RPDs less than 100%	1/8	0/8	0/8	0/8
Number RPDs less than 400%	5/8	2/8	2/8	2/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww)				
Mean RPD	826%	1,101%	1,166%	1,260%
Median RPD	347%	941%	445%	990%
Number RPDs less than 100%	1/8	0/8	0/8	0/8
Number RPDs less than 400%	6/8	2/8	4/8	3/8
Comparison to maximum concentrations of total PCBs (µg/kg ww)				
Mean RPD	126%	199%	208%	250%
Median RPD	15%	103%	56%	126%
Number RPDs less than 100%	5/8	4/8	4/8	2/8
Number RPDs less than 400%	7/8	6/8	7/8	6/8

RPD – relative percent difference

Table 4-6. Summary of sensitivity and uncertainty analyses for Arnot and Gobas model

	SENSITIVITY ANALYSIS						UNCERTAINTY ANALYSIS				
	PREDICTED CONC. (µg/kg) FOR SCENARIO 6l	BIOTA LIPIDS	BIOTA WEIGHTS	SEDIMENT OC (1.72%)	PCB CONC. IN SEDIMENT (560 µg/kg)	PCB CONC. IN WATER (2.2 ng/L)	NLOC FOR PHYTOPLANKTON (6.8%)	OLIGOCHAETE LIPIDS (1%)	PCB CONC. IN SEDIMENT (479 µg/kg)	PCB CONC. IN WATER (400 ng/L)	PCB CONC. IN WATER (0.07 ng/L)
Mollusk	119	123	118	116	122	128	117	119	117	17,358	35
Oligochaete	599	622	598	586	612	645	582	206	591	93,052	150
Aquatic insect	176	183	175	171	181	188	175	176	173	25,221	54
Amphipod	131	135	131	128	134	141	130	131	129	19,461	37

	Sensitivity Analysis						Uncertainty Analysis				
	Predicted Conc. (µg/kg) for Scenario 6l	**Biota Lipids**	**Biota Weights**	**Sediment OC (1.72%)**	**PCB Conc. in Sediment (560 µg/kg)**	**PCB Conc. in Water (2.2 ng/L)**	**NLOC for Phytoplankton (6.8%)**	**Oligochaete Lipids (1%)**	**PCB Conc. in Sediment (479 µg/kg)**	**PCB Conc. in water (400 ng/L)**	**PCB Conc. in water (0.07 ng/L)**
Crayfish	362	367	362	355	369	391	360	374	358	57,584	85
Carp	2,118	2,216	2,123	2,079	2,158	2,287	2,203	2,174	2093	341,296	473
Largescale sucker	1,020	1,076	1,021	1,002	1,039	1,102	1,055	897	1,008	165,550	222
Juvenile chinook salmon	953	1,013	954	933	974	1,026	946	969	940	147,338	243
Sculpin	1,288	1,380	1,290	1,261	1,316	1,387	1,276	1,055	1,270	199,443	327
Peamouth	755	790	755	745	767	819	766	755	749	128,120	138
Black crappie	5,352	5,822	5,377	5,247	5,464	5,772	5,367	4,668	5,285	843,611	1,287
Brown bullhead	921	988	922	901	943	991	916	923	908	139,991	247
Smallmouth bass	5,203	5,668	5,227	5,099	5,315	5,609	5,214	4,492	5,137	815,795	1273
Northern pikeminnow	3,398	3,685	3,411	3,329	3,472	3,662	3,422	3,060	3,354	530,734	841
Comparison of predicted concentrations of total PCBs (µg/kg ww) under scenario 6l as relative percent difference (RPD) to predicted concentrations from each model run with the parameter change indicated above											
Mollusk	0%	3%	-0.7%	-3%	3%	7%	-1%	0%	-2%	14,493%	-70%
Oligochaete	0%	4%	-0.2%	-2%	2%	8%	-3%	-66%	-1%	15,441%	-75%
Aquatic insect	0%	4%	-0.5%	-3%	3%	7%	-1%	0%	-2%	14,259%	-69%
Amphipod	0%	3%	-0.2%	-2%	3%	7%	-1%	0%	-2%	14,746%	-72%
Crayfish	0%	1%	0.0%	-2%	2%	8%	-1%	3%	-1%	15,803%	-77%
Carp	0%	5%	0.3%	-2%	2%	8%	4%	3%	-1%	16,018%	-78%
Largescale sucker	0%	6%	0.1%	-2%	2%	8%	3%	-12%	-1%	16,133%	-78%
Juvenile chinook salmon	0%	6%	0.2%	-2%	2%	8%	-1%	2%	-1%	15,367%	-75%
Sculpin	0%	7%	0.2%	-2%	2%	8%	-1%	-18%	-1%	15,390%	-75%
Peamouth	0%	5%	-0.1%	-1%	2%	8%	1%	0%	-1%	16,860%	-82%
Black crappie	0%	9%	0.5%	-2%	2%	8%	0%	-13%	-1%	15,663%	-76%
Brown bullhead	0%	7%	0.1%	-2%	2%	8%	-1%	0%	-1%	15,098%	-73%
Smallmouth bass	0%	9%	0.5%	-2%	2%	8%	0%	-14%	-1%	15,578%	-76%
Northern pikeminnow	0%	8%	0.4%	-2%	2%	8%	1%	-10%	-1%	15,519%	-75%
Mean RPD	**0%**	**6%**	**0.0%**	**-2%**	**2%**	**8%**	**0%**	**-9%**	**-1%**	**15,455%**	**-75%**
Median RPD	**0%**	**5%**	**0.1%**	**-2%**	**2%**	**8%**	**-1%**	**0%**	**-1%**	**15,480%**	**-75%**

OC – organic carbon
na – not applicable
RPD – relative percent difference

Table 4-7. Summary of best-performing scenarios for TrophicTrace model

Scenario	**3B**	**6B**
Comparison to mean concentrations of total PCBs (µg/kg ww)		
Mean RPD	-19%	25%
Median RPD	-44%	-32%
Number RPDs less than 100%	7/8	7/8
Number RPDs less than 400%	8/8	7/8
Comparison to median concentrations of total PCBs (µg/kg ww)		
Mean RPD	27%	91%
Median RPD	8%	-7%
Number RPDs less than 100%	7/8	6/8
Number RPDs less than 400%	8/8	7/8
Comparison to geometric mean concentrations of total PCBs (µg/kg ww)		
Mean RPD	10%	63%
Median RPD	2%	-7%
Number RPDs less than 100%	7/8	6/8
Number RPDs less than 400%	8/8	7/8
Comparison to maximum concentrations of total PCBs (µg/kg ww)		
Mean RPD	-63%	-44%
Median RPD	-81%	-80%
Number RPDs less than 100%	8/8	7/8
Number RPDs less than 400%	8/8	8/8

RPD—relative percent difference

Table 4-8a. Summary of sensitivity and uncertainty analyses for TrophicTrace model (scenario 3b)

	Original Predicted Conc. of Total PCBs (µg/kg ww)	Uncertainty Analysis				Sensitivity Analysis - 10% parameter increase				
		PCB Conc. in Sediment (479 µg/kg)	Oligochaete % Lipid Content (1%)	PCB Conc. in Water (400 ng/L)	PCB Conc. in Water (0.07 ng/L)	Biota Weights	Biota Lipids	PCB Conc. in Sediment (560 µg/kg)	Sediment Organic Carbon (1.72%)	PCB Conc. in Water (2.2 ng/l)
Black crappie	292	279	292	12800	231	294	320	315	271	298
Brown bullhead	247	235	247	9310	203	249	271	267	228	252
Carp	379	358	379	2350	369	381	413	416	345	380
Largescale sucker	674	637	255	8810	635	677	741	738	615	679
Northern pikeminnow	417	396	357	13200	355	420	458	453	384	424
Peamouth	258	247	258	11800	203	260	282	279	240	264
Sculpin	242	231	242	10600	192	243	266	261	224	247
Smallmouth bass	398	380	331	17000	318	401	437	430	369	407
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD										
Black crappie	na	-4%	0%	4284%	-21%	1%	9%	8%	-7%	2%
Brown bullhead	na	-5%	0%	3669%	-18%	1%	10%	8%	-8%	2%
Carp	na	-6%	0%	520%	-3%	0%	9%	10%	-9%	0%
Largescale sucker	na	-5%	-62%	1207%	-6%	0%	10%	9%	-9%	1%
Northern pikeminnow	na	-5%	-14%	3065%	-15%	1%	10%	9%	-8%	2%
Peamouth	na	-4%	0%	4474%	-21%	1%	9%	8%	-7%	2%
Sculpin	na	-5%	0%	4280%	-21%	1%	10%	8%	-7%	2%
Smallmouth bass	na	-5%	-17%	4171%	-20%	1%	10%	8%	-7%	2%
Mean RPD	**na**	**-5%**	**-12%**	**3209%**	**-16%**	**1%**	**10%**	**8%**	**-8%**	**2%**
Median RPD	**na**	**-5%**	**0%**	**3920%**	**-19%**	**1%**	**10%**	**8%**	**-8%**	**2%**

na – not applicable
RPD – relative percent difference

Table 4-8b. Summary of sensitivity and uncertainty analyses for TrophicTrace model (scenario 6b)

		Uncertainty Analysis				Sensitivity Analysis 10% parameter increase				
	Predicted Conc. of Total PCBs (µg/kg ww)	**PCB Conc. in Sediment (479 µg/kg)**	**Oligochaete % Lipid Content (1%)**	**PCB Conc. in Water (400 ng/L)**	**PCB Conc. in Water (0.07 ng/L)**	**Biota Weights**	**Biota Lipids**	**PCB Conc. in Sediment (560 µg/kg)**	**Sediment Organic Carbon (1.72%)**	**PCB Conc. in Water (2.2 ng/l)**
Black crappie	747	707	373	11800	694	755	832	817	683	753
Brown bullhead	199	190	196	8310	160	200	218	215	184	203
Carp	228	216	228	4830	205	229	245	248	209	230
Largescale sucker	310	293	205	4260	290	311	341	339	283	312
Northern pikeminnow	596	564	271	10000	550	600	658	651	545	600
Peamouth	125	119	125	5040	101	125	137	135	116	128
Sculpin	743	701	309	6350	716	748	825	815	676	746
Smallmouth bass	771	730	384	11700	718	779	858	844	705	777
Comparison to mean concentrations of total PCBs (µg/kg ww) as RPD										
Black crappie	na	-5%	-50%	1480%	-7%	1%	11%	9%	-9%	1%
Brown bullhead	na	-5%	-2%	4076%	-20%	1%	10%	8%	-8%	2%
Carp	na	-5%	0%	2018%	-10%	0%	7%	9%	-8%	1%
Largescale sucker	na	-5%	-34%	1274%	-6%	0%	10%	9%	-9%	1%
Northern pikeminnow	na	-5%	-55%	1578%	-8%	1%	10%	9%	-9%	1%
Peamouth	na	-5%	0%	3932%	-19%	0%	10%	8%	-7%	2%
Sculpin	na	-6%	-58%	755%	-4%	1%	11%	10%	-9%	0%
Smallmouth bass	na	-5%	-50%	1418%	-7%	1%	11%	9%	-9%	1%
Mean RPD	**na**	**-5%**	**-31%**	**2066%**	**-10%**	**1%**	**10%**	**9%**	**-8%**	**1%**
Median RPD	**na**	**-5%**	**-42%**	**1529%**	**-7%**	**1%**	**10%**	**9%**	**-9%**	**1%**

na – not applicable
RPD – relative percent difference

Table 4-9. Evaluation and comparison of models

	Model Suitability to Portland Harbor	Fit Between Predicted and Observed Values	Data Requirements	Acceptability of Assumptions and Uncertainty	Ease of Model Construction and Implementation
Campfens and Mackay	Past applications in lakes. Limited to 9 biota compartments (thus no phytoplankton or zooplankton in any food web). Could not include sediment in the diet. Cannibalism is possible however was not explored to be consistent with other models.	Predictions were off by many orders of magnitude.	Moderate level, acceptable. Used default values for many input parameters.	Rate constants are derived from old empirical values and relationships. Invertebrate chemical uptake is from water and sediment-associated pore water (no dietary uptake). Fish uptake is from water (via gills) and the diet.	Difficult to enter items into the model (old Basic program) Fugacity calculations and conversions were awkward.
Gobas	Past application in lakes, fjords, and bay-estuaries (dynamic version in a river). Model incorporated all 9 fish species, 5 invertebrates (out of a possible 7) and zooplankton and phytoplankton.	Best result was Scenario 3k; 2 of 8 fish species within a factor of two, and 6 of 8 fish species within a factor of five.	Major input parameters were relatively easy to research. Fewer input parameters than Arnot and Gobas.	Oversimplifies the process of chemical uptake for individual invertebrates by assuming all invertebrates are sediment-based and all chemical uptake is from the sediment.	Excel®-based format makes it user-friendly.
Arnot and Gobas	Past applications in lakes. Model incorporated all 9 fish species, 5 invertebrates (out of a possible 7) and zooplankton and phytoplankton. Does not allow cannibalism or consumption of any species placed above it in the species list (invertebrates and fish were listed by trophic level based on all six food web matrices).	Best result was Scenario 6l; 2 of 8 fish species within a factor of 2, and 7 of 8 fish species within a factor of 5	Major input parameters were relatively easy to research. Some of the input parameters for which default settings were used are more difficult to derive or find empirical for e.g. fraction of overlying water ventilated and fraction of pore water ventilated.	Model calculates gill ventilation rates and food consumption rates using new constants and relationships derived from recent studies. Includes a mechanistic model for predicting gastro-intestinal magnification of organic chemicals in a range of species. Assumptions are for more complex processes but assumptions are not more numerous than the other models.	Excel®-based format makes it user-friendly.
Trophic-Trace	Past application in lakes, rivers and estuaries. Model was limited to 17 biota compartments and 10 dietary items.	Best result was Scenario 3b; 7 of 8 fish species within a factor of 2, and 8 of 8 fish species within a factor of 5. Best scenarios were under predicting.	Very simple input parameters. Rate constants are derived from fixed values so input parameters are fewer than for Arnot and Gobas.	Chemical uptake for individual invertebrates is either from the water or sediment. Rate constants are derived from old empirical values and relationships. To have sediment in the diet a BSAF of 1 must be used for all sediment-based invertebrates.	Excel®-based format makes it user-friendly.
Common to all models	Do not allow species to consume potential predators. Solution: create size/age classes of fish	All models except TrophicTrace consistently over-predicted.	All models had some parameters which were difficult to derive or find supporting values in the literature for default values.	Species were combined to fit into the limited biota compartments. The theory of Campfens and Mackay, TrophicTrace, and Gobas are the same, but the actual mechanisms and equations are different.	Used preexisting constructs.